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(54) **ANALYTE SENSOR WITH TIME LAG COMPENSATION**

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CPC ***A61B 5/1495*** (2013.01); ***A61B 5/1468*** (2013.01); ***A61B 5/14532*** (2013.01); ***A61B 5/14546*** (2013.01); *A61B 2560/0223* (2013.01)

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CPC A61B 5/14503; A61B 5/04532; A61B 5/14568; A61B 5/1473; A61B 5/1495; A61B 2560/0223

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,581,062	A	5/1971	Aston
3,926,760	A	12/1975	Allen et al.
3,949,388	A	4/1976	Fuller
3,960,497	A	6/1976	Acord et al.
4,033,330	A	7/1977	Willis et al.
4,036,749	A	7/1977	Anderson
4,055,175	A	10/1977	Clemens et al.
4,129,128	A	12/1978	McFarlane
4,245,634	A	1/1981	Albisser et al.
4,327,725	A	5/1982	Cortese et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE	4401400	7/1995
EP	0098592	1/1984

(Continued)

OTHER PUBLICATIONS

Armour, J. C., et al., "Application of Chronic Intravascular Blood Glucose Sensor in Dogs", *Diabetes*, vol. 39, 1990, pp. 1519-1526.

(Continued)

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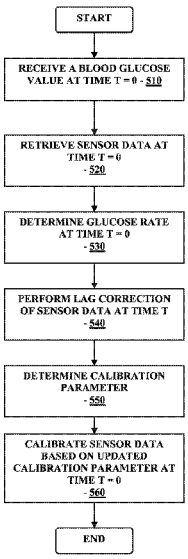
(57) **ABSTRACT**

Methods and devices and systems for determining an analyte value are disclosed.

13 Claims, 8 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,344,438 A 8/1982 Schultz
4,349,728 A 9/1982 Phillips et al.
4,373,527 A 2/1983 Fischell
4,392,849 A 7/1983 Petre et al.
4,425,920 A 1/1984 Bourland et al.
4,431,004 A 2/1984 Bessman et al.
4,441,968 A 4/1984 Emmer et al.
4,464,170 A 8/1984 Clemens et al.
4,478,976 A 10/1984 Goertz et al.
4,494,950 A 1/1985 Fischell
4,509,531 A 4/1985 Ward
4,527,240 A 7/1985 Kvitash
4,538,616 A 9/1985 Rogoff
4,619,793 A 10/1986 Lee
4,671,288 A 6/1987 Gough
4,703,756 A 11/1987 Gough et al.
4,731,726 A 3/1988 Allen, III
4,749,985 A 6/1988 Corsberg
4,757,022 A 7/1988 Shults et al.
4,777,953 A 10/1988 Ash et al.
4,779,618 A 10/1988 Mund et al.
4,847,785 A 7/1989 Stephens
4,854,322 A 8/1989 Ash et al.
4,871,351 A 10/1989 Feingold
4,890,620 A 1/1990 Gough
4,925,268 A 5/1990 Iyer et al.
4,953,552 A 9/1990 DeMarzo
4,986,271 A 1/1991 Wilkins
4,995,402 A 2/1991 Smith et al.
5,000,180 A 3/1991 Kuypers et al.
5,002,054 A 3/1991 Ash et al.
5,019,974 A 5/1991 Beckers
5,050,612 A 9/1991 Matsumura
5,051,688 A 9/1991 Murase et al.
5,055,171 A 10/1991 Peck
5,068,536 A 11/1991 Rosenthal
5,082,550 A 1/1992 Rishpon et al.
5,106,365 A 4/1992 Hernandez
5,122,925 A 6/1992 Inpyn
5,135,004 A 8/1992 Adams et al.
5,165,407 A 11/1992 Wilson et al.
5,202,261 A 4/1993 Musho et al.
5,204,264 A 4/1993 Kaminer et al.
5,210,778 A 5/1993 Massart
5,228,449 A 7/1993 Christ et al.
5,231,988 A 8/1993 Wernicke et al.
5,246,867 A 9/1993 Lakowicz et al.
5,251,126 A 10/1993 Kahn et al.
5,262,035 A 11/1993 Gregg et al.
5,262,305 A 11/1993 Heller et al.
5,264,104 A 11/1993 Gregg et al.
5,264,105 A 11/1993 Gregg et al.
5,279,294 A 1/1994 Anderson et al.
5,285,792 A 2/1994 Sjoquist et al.
5,293,877 A 3/1994 O'Hara et al.
5,299,571 A 4/1994 Mastrototaro
5,320,725 A 6/1994 Gregg et al.
5,322,063 A 6/1994 Allen et al.
5,330,634 A 7/1994 Wong et al.
5,340,722 A 8/1994 Wolfbeis et al.
5,342,789 A 8/1994 Chick et al.
5,356,786 A 10/1994 Heller et al.
5,360,404 A 11/1994 Novacek et al.
5,372,427 A 12/1994 Padovani et al.
5,379,238 A 1/1995 Stark
5,384,547 A 1/1995 Lynk et al.
5,390,671 A 2/1995 Lord et al.
5,391,250 A 2/1995 Cheney, II et al.
5,408,999 A 4/1995 Singh et al.
5,410,326 A 4/1995 Goldstein
5,411,647 A 5/1995 Johnson et al.
5,425,868 A 6/1995 Pedersen
5,429,602 A 7/1995 Hauser
5,431,160 A 7/1995 Wilkins
5,431,921 A 7/1995 Thombre
5,438,983 A 8/1995 Falcone
5,462,645 A 10/1995 Albery et al.
5,472,317 A 12/1995 Field et al.
5,489,414 A 2/1996 Schreiber et al.
5,497,772 A 3/1996 Schulman et al.
5,505,828 A 4/1996 Wong et al.
5,507,288 A 4/1996 Bocker et al.
5,509,410 A 4/1996 Hill et al.
5,514,718 A 5/1996 Lewis et al.
5,531,878 A 7/1996 Vadgama et al.
5,552,997 A 9/1996 Massart
5,555,190 A 9/1996 Derby et al.
5,568,400 A 10/1996 Stark et al.
5,568,806 A 10/1996 Cheney, II et al.
5,569,186 A 10/1996 Lord et al.
5,582,184 A 12/1996 Erickson et al.
5,586,553 A 12/1996 Halili et al.
5,593,852 A 1/1997 Heller et al.
5,601,435 A 2/1997 Quy
5,609,575 A 3/1997 Larson et al.
5,628,310 A 5/1997 Rao et al.
5,628,324 A 5/1997 Sarbach
5,653,239 A 8/1997 Pompei et al.
5,660,163 A 8/1997 Schulman et al.
5,665,222 A 9/1997 Heller et al.
5,711,001 A 1/1998 Bussan et al.
5,711,861 A 1/1998 Ward et al.
5,726,646 A 3/1998 Bane et al.
5,733,259 A 3/1998 Valcke et al.
5,735,285 A 4/1998 Albert et al.
5,748,103 A 5/1998 Flach et al.
5,772,586 A 6/1998 Heinonen et al.
5,791,344 A 8/1998 Schulman et al.
5,833,603 A 11/1998 Kovacs et al.
5,842,189 A 11/1998 Keeler et al.
5,899,855 A 5/1999 Brown
5,914,026 A 6/1999 Blubaugh, Jr. et al.
5,919,141 A 7/1999 Money et al.
5,925,021 A 7/1999 Castellano et al.
5,935,224 A 8/1999 Svancarek et al.
5,942,979 A 8/1999 Luppino
5,957,854 A 9/1999 Besson et al.
5,961,451 A 10/1999 Reber et al.
5,964,993 A 10/1999 Blubaugh, Jr. et al.
5,965,380 A 10/1999 Heller et al.
5,971,922 A 10/1999 Arita et al.
5,980,708 A 11/1999 Champagne et al.
5,995,860 A 11/1999 Sun et al.
6,001,067 A 12/1999 Shults et al.
6,024,699 A 2/2000 Surwit et al.
6,028,413 A 2/2000 Brockmann
6,049,727 A 4/2000 Crothall
6,052,565 A 4/2000 Ishikura et al.
6,066,243 A 5/2000 Anderson et al.
6,083,710 A 7/2000 Heller et al.
6,088,608 A 7/2000 Schulman et al.
6,091,976 A 7/2000 Pfeiffer et al.
6,093,172 A 7/2000 Funderburk et al.
6,096,364 A 8/2000 Bok et al.
6,103,033 A 8/2000 Say et al.
6,117,290 A 9/2000 Say et al.
6,119,028 A 9/2000 Schulman et al.
6,120,676 A 9/2000 Heller et al.
6,121,009 A 9/2000 Heller et al.
6,121,611 A 9/2000 Lindsay et al.
6,122,351 A 9/2000 Schlueter, Jr. et al.
6,134,461 A 10/2000 Say et al.
6,143,164 A 11/2000 Heller et al.
6,157,850 A 12/2000 Diab et al.
6,159,147 A 12/2000 Lichter et al.
6,162,611 A 12/2000 Heller et al.
6,175,752 B1 1/2001 Say et al.
6,200,265 B1 3/2001 Walsh et al.
6,212,416 B1 4/2001 Ward et al.
6,219,574 B1 4/2001 Cormier et al.
6,223,283 B1 4/2001 Chaiken et al.
6,233,471 B1 5/2001 Berner et al.
6,248,067 B1 6/2001 Causey, III et al.
6,254,586 B1 7/2001 Mann et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,270,455 B1 8/2001 Brown
6,275,717 B1 8/2001 Gross et al.
6,283,761 B1 9/2001 Joao
6,284,478 B1 9/2001 Heller et al.
6,293,925 B1 9/2001 Safabash et al.
6,295,506 B1 9/2001 Heinonen et al.
6,299,347 B1 10/2001 Pompei
6,306,104 B1 10/2001 Cunningham et al.
6,309,884 B1 10/2001 Cooper et al.
6,314,317 B1 11/2001 Willis
6,329,161 B1 12/2001 Heller et al.
6,348,640 B1 2/2002 Navot et al.
6,359,270 B1 3/2002 Bridson
6,359,444 B1 3/2002 Grimes
6,360,888 B1 3/2002 McIvor et al.
6,366,794 B1 4/2002 Moussy et al.
6,377,828 B1 4/2002 Chaiken et al.
6,379,301 B1 4/2002 Worthington et al.
6,387,048 B1 5/2002 Schulman et al.
6,424,847 B1 7/2002 Mastrototaro et al.
6,427,088 B1 7/2002 Bowman, IV et al.
6,440,068 B1 8/2002 Brown et al.
6,471,689 B1 10/2002 Joseph et al.
6,478,736 B1 11/2002 Mault
6,484,046 B1 11/2002 Say et al.
6,493,069 B1 12/2002 Nagashimada et al.
6,498,043 B1 12/2002 Schulman et al.
6,514,718 B2 2/2003 Heller et al.
6,544,212 B2 4/2003 Galley et al.
6,546,268 B1 4/2003 Ishikawa et al.
6,551,494 B1 4/2003 Heller et al.
6,554,798 B1 4/2003 Mann et al.
6,558,320 B1 5/2003 Causey, III et al.
6,558,321 B1 5/2003 Burd et al.
6,558,351 B1 5/2003 Steil et al.
6,560,471 B1 5/2003 Heller et al.
6,561,978 B1 5/2003 Conn et al.
6,562,001 B2 5/2003 Lebel et al.
6,564,105 B2 5/2003 Starkweather et al.
6,565,509 B1 5/2003 Say et al.
6,571,128 B2 5/2003 Lebel et al.
6,572,545 B2 6/2003 Knobbe et al.
6,574,490 B2 6/2003 Abbink et al.
6,576,101 B1 6/2003 Heller et al.
6,577,899 B2 6/2003 Lebel et al.
6,579,690 B1 6/2003 Bonnecaze et al.
6,585,644 B2 7/2003 Lebel et al.
6,591,125 B1 7/2003 Buse et al.
6,595,919 B2 7/2003 Berner et al.
6,605,200 B1 8/2003 Mao et al.
6,605,201 B1 8/2003 Mao et al.
6,607,509 B2 8/2003 Bobroff et al.
6,610,012 B2 8/2003 Mault
6,633,772 B2 10/2003 Ford et al.
6,635,014 B2 10/2003 Starkweather et al.
6,641,533 B2 11/2003 Causey, III et al.
6,648,821 B2 11/2003 Lebel et al.
6,654,625 B1 11/2003 Say et al.
6,656,114 B1 12/2003 Poulsen et al.
6,658,396 B1 12/2003 Tang et al.
6,659,948 B2 12/2003 Lebel et al.
6,668,196 B1 12/2003 Villegas et al.
6,675,030 B2 1/2004 Ciuczak et al.
6,676,816 B2 1/2004 Mao et al.
6,687,546 B2 2/2004 Lebel et al.
6,689,056 B1 2/2004 Kilcoyne et al.
6,694,191 B2 2/2004 Starkweather et al.
6,695,860 B1 2/2004 Ward et al.
6,698,269 B2 3/2004 Baber et al.
6,702,857 B2 3/2004 Brauker et al.
6,730,025 B1 5/2004 Platt
6,733,446 B2 5/2004 Lebel et al.
6,740,075 B2 5/2004 Lebel et al.
6,740,518 B1 5/2004 Duong et al.
6,741,877 B1 5/2004 Shults et al.
6,746,582 B2 6/2004 Heller et al.
6,758,810 B2 7/2004 Lebel et al.
6,770,030 B1 8/2004 Schaupp et al.
6,789,195 B1 9/2004 Prihoda et al.
6,790,178 B1 9/2004 Mault et al.
6,809,653 B1 10/2004 Mann et al.
6,810,290 B2 10/2004 Lebel et al.
6,811,533 B2 11/2004 Lebel et al.
6,811,534 B2 11/2004 Bowman, IV et al.
6,813,519 B2 11/2004 Lebel et al.
6,850,790 B2 2/2005 Berner et al.
6,862,465 B2 3/2005 Shults et al.
6,865,407 B2 3/2005 Kimball et al.
6,873,268 B2 3/2005 Lebel et al.
6,881,551 B2 4/2005 Heller et al.
6,882,940 B2 4/2005 Potts et al.
6,892,085 B2 5/2005 McIvor et al.
6,895,263 B2 5/2005 Shin et al.
6,895,265 B2 5/2005 Silver
6,923,763 B1 8/2005 Kovatchev et al.
6,931,327 B2 8/2005 Goode, Jr. et al.
6,932,894 B2 8/2005 Mao et al.
6,936,006 B2 8/2005 Sabra
6,942,518 B2 9/2005 Liamos et al.
6,950,708 B2 9/2005 Bowman, IV et al.
6,958,705 B2 10/2005 Lebel et al.
6,968,294 B2 11/2005 Gutta et al.
6,971,274 B2 12/2005 Olin
6,974,437 B2 12/2005 Lebel et al.
6,983,176 B2 1/2006 Gardner et al.
6,990,366 B2 1/2006 Say et al.
6,997,907 B2 2/2006 Safabash et al.
6,998,247 B2 2/2006 Monfre et al.
6,999,854 B2 2/2006 Roth
7,003,336 B2 2/2006 Holker et al.
7,003,340 B2 2/2006 Say et al.
7,003,341 B2 2/2006 Say et al.
7,015,817 B2 3/2006 Copley et al.
7,016,713 B2 3/2006 Gardner et al.
7,022,072 B2 4/2006 Fox et al.
7,022,219 B2 4/2006 Mansouri et al.
7,024,245 B2 4/2006 Lebel et al.
7,025,425 B2 4/2006 Kovatchev et al.
7,027,848 B2 4/2006 Robinson et al.
7,027,931 B1 4/2006 Jones et al.
7,029,444 B2 4/2006 Shin et al.
7,041,068 B2 5/2006 Freeman et al.
7,041,468 B2 5/2006 Drucker et al.
7,046,153 B2 5/2006 Oja et al.
7,052,483 B2 5/2006 Wojcik
7,056,302 B2 6/2006 Douglas
7,074,307 B2 7/2006 Simpson et al.
7,081,195 B2 7/2006 Simpson et al.
7,092,891 B2 8/2006 Maus et al.
7,098,803 B2 8/2006 Mann et al.
7,108,778 B2 9/2006 Simpson et al.
7,110,803 B2 9/2006 Shults et al.
7,113,821 B1 9/2006 Sun et al.
7,118,667 B2 10/2006 Lee
7,123,950 B2 10/2006 Mannheimer
7,134,999 B2 11/2006 Brauker et al.
7,136,689 B2 11/2006 Shults et al.
7,153,265 B2 12/2006 Vachon
7,155,290 B2 12/2006 Von Arx et al.
7,167,818 B2 1/2007 Brown
7,171,274 B2 1/2007 Starkweather et al.
7,174,199 B2 2/2007 Berner et al.
7,179,226 B2 2/2007 Crothall et al.
7,190,988 B2 3/2007 Say et al.
7,192,450 B2 3/2007 Brauker et al.
7,198,606 B2 4/2007 Boecker et al.
7,207,974 B2 4/2007 Safabash et al.
7,225,535 B2 6/2007 Feldman et al.
7,226,442 B2 6/2007 Sheppard et al.
7,226,978 B2 6/2007 Tapsak et al.
7,258,673 B2 8/2007 Racchini et al.
7,267,665 B2 9/2007 Steil et al.
7,276,029 B2 10/2007 Goode, Jr. et al.
7,278,983 B2 10/2007 Ireland et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,286,894 B1 10/2007 Grant et al.
7,299,082 B2 11/2007 Feldman et al.
7,310,544 B2 12/2007 Brister et al.
7,317,938 B2 1/2008 Lorenz et al.
7,335,294 B2 2/2008 Heller et al.
7,354,420 B2 4/2008 Steil et al.
7,364,592 B2 4/2008 Carr-Brendel et al.
7,366,556 B2 4/2008 Brister et al.
7,379,765 B2 5/2008 Petisce et al.
7,402,153 B2 7/2008 Steil et al.
7,404,796 B2 7/2008 Ginsberg
7,424,318 B2 9/2008 Brister et al.
7,460,898 B2 12/2008 Brister et al.
7,467,003 B2 12/2008 Brister et al.
7,468,125 B2 12/2008 Kraft et al.
7,471,972 B2 12/2008 Rhodes et al.
7,474,992 B2 1/2009 Ariyur
7,494,465 B2 2/2009 Brister et al.
7,497,827 B2 3/2009 Brister et al.
7,519,408 B2 4/2009 Rasdal et al.
7,547,281 B2 6/2009 Hayes et al.
7,569,030 B2 8/2009 Lebel et al.
7,583,990 B2 9/2009 Goode, Jr. et al.
7,591,801 B2 9/2009 Brauker et al.
7,599,726 B2 10/2009 Goode, Jr. et al.
7,613,491 B2 11/2009 Boock et al.
7,615,007 B2 11/2009 Shults et al.
7,618,369 B2 11/2009 Hayter et al.
7,630,748 B2 12/2009 Budiman
7,632,228 B2 12/2009 Brauker et al.
7,635,594 B2 12/2009 Holmes et al.
7,637,868 B2 12/2009 Saint et al.
7,640,048 B2 12/2009 Dobbles et al.
7,651,596 B2 1/2010 Petisce et al.
7,651,845 B2 1/2010 Doyle, III et al.
7,653,425 B2 1/2010 Hayter et al.
7,654,956 B2 2/2010 Brister et al.
7,657,297 B2 2/2010 Simpson et al.
7,699,775 B2 4/2010 Desai et al.
7,699,964 B2 4/2010 Feldman et al.
7,711,402 B2 5/2010 Shults et al.
7,713,574 B2 5/2010 Brister et al.
7,715,893 B2 5/2010 Kamath et al.
7,736,310 B2 6/2010 Taub et al.
7,766,829 B2 8/2010 Sloan et al.
7,768,386 B2 8/2010 Hayter et al.
7,768,387 B2 8/2010 Fennell et al.
7,771,352 B2 8/2010 Shults et al.
7,775,444 B2 8/2010 DeRocco et al.
7,778,680 B2 8/2010 Goode et al.
7,783,333 B2 8/2010 Brister et al.
7,792,562 B2 9/2010 Shults et al.
7,811,231 B2 10/2010 Jin et al.
7,813,809 B2 10/2010 Strother et al.
7,826,382 B2 11/2010 Sicurello et al.
7,826,981 B2 11/2010 Goode, Jr. et al.
7,889,069 B2 2/2011 Fifolt et al.
7,899,511 B2 3/2011 Shults et al.
7,899,545 B2 3/2011 John
7,905,833 B2 3/2011 Brister et al.
7,914,450 B2 3/2011 Goode, Jr. et al.
7,920,906 B2 4/2011 Goode et al.
7,928,850 B2 4/2011 Hayter et al.
7,938,797 B2 5/2011 Estes
7,941,200 B2 5/2011 Weinert et al.
7,946,985 B2 5/2011 Mastrototaro et al.
7,970,448 B2 6/2011 Shults et al.
7,972,296 B2 7/2011 Braig et al.
7,974,672 B2 7/2011 Shults et al.
7,976,466 B2 7/2011 Ward et al.
7,978,063 B2 7/2011 Baldus et al.
8,010,174 B2 8/2011 Goode et al.
8,010,256 B2 8/2011 Oowada
8,160,900 B2 4/2012 Taub et al.
8,192,394 B2 6/2012 Estes et al.
8,216,138 B1 7/2012 McGarraugh et al.
8,255,026 B1 8/2012 Al-Ali
8,282,549 B2 10/2012 Brauker et al.
8,374,668 B1 2/2013 Hayter et al.
8,461,985 B2 6/2013 Fennell et al.
8,478,557 B2 7/2013 Hayter et al.
8,597,570 B2 12/2013 Terashima et al.
8,710,993 B2 4/2014 Hayter et al.
8,845,536 B2 9/2014 Brauker et al.
2001/0037366 A1 11/2001 Webb et al.
2002/0019022 A1 2/2002 Dunn et al.
2002/0042090 A1 4/2002 Heller et al.
2002/0054320 A1 5/2002 Ogino
2002/0068860 A1 6/2002 Clark
2002/0095076 A1 7/2002 Krausman et al.
2002/0103499 A1 8/2002 Perez et al.
2002/0106709 A1 8/2002 Potts et al.
2002/0117639 A1 8/2002 Paolini et al.
2002/0120186 A1 8/2002 Keimel
2002/0128594 A1 9/2002 Das et al.
2002/0147135 A1 10/2002 Schnell
2002/0161288 A1 10/2002 Shin et al.
2002/0169635 A1 11/2002 Shillingburg
2003/0004403 A1 1/2003 Drinan et al.
2003/0023317 A1 1/2003 Brauker et al.
2003/0023461 A1 1/2003 Quintanilla et al.
2003/0028089 A1 2/2003 Galley et al.
2003/0032077 A1 2/2003 Itoh et al.
2003/0032867 A1 2/2003 Crothall et al.
2003/0032874 A1 2/2003 Rhodes et al.
2003/0042137 A1 3/2003 Mao et al.
2003/0060692 A1 3/2003 Ruchti et al.
2003/0060753 A1 3/2003 Starkweather et al.
2003/0065308 A1 4/2003 Lebel et al.
2003/0100040 A1 5/2003 Bonnecaze et al.
2003/0100821 A1 5/2003 Heller et al.
2003/0114897 A1 6/2003 Von Arx et al.
2003/0125612 A1 7/2003 Fox et al.
2003/0130616 A1 7/2003 Steil et al.
2003/0134347 A1 7/2003 Heller et al.
2003/0147515 A1 8/2003 Kai et al.
2003/0168338 A1 9/2003 Gao et al.
2003/0176933 A1 9/2003 Lebel et al.
2003/0187338 A1 10/2003 Say et al.
2003/0191377 A1 10/2003 Robinson et al.
2003/0199744 A1 10/2003 Buse et al.
2003/0199790 A1 10/2003 Boecker et al.
2003/0208113 A1 11/2003 Mault et al.
2003/0212317 A1 11/2003 Kovatchev et al.
2003/0212379 A1 11/2003 Bylund et al.
2003/0216630 A1 11/2003 Jersey-Willuhn et al.
2003/0217966 A1 11/2003 Tapsak et al.
2004/0010186 A1 1/2004 Kimball et al.
2004/0010207 A1 1/2004 Flaherty et al.
2004/0011671 A1 1/2004 Shults et al.
2004/0024553 A1 2/2004 Monfre et al.
2004/0034289 A1 2/2004 Teller et al.
2004/0039298 A1 2/2004 Abreu
2004/0040840 A1 3/2004 Mao et al.
2004/0041749 A1 3/2004 Dixon
2004/0045879 A1 3/2004 Shults et al.
2004/0054263 A1 3/2004 Moerman et al.
2004/0063435 A1 4/2004 Sakamoto et al.
2004/0064068 A1 4/2004 DeNuzzio et al.
2004/0099529 A1 5/2004 Mao et al.
2004/0106858 A1 6/2004 Say et al.
2004/0117204 A1 6/2004 Mazar et al.
2004/0122353 A1 6/2004 Shahmirian et al.
2004/0133164 A1 7/2004 Funderburk et al.
2004/0133390 A1 7/2004 Osorio et al.
2004/0135571 A1 7/2004 Uutela et al.
2004/0135684 A1 7/2004 Steinthal et al.
2004/0138588 A1 7/2004 Saikley et al.
2004/0146909 A1 7/2004 Duong et al.
2004/0147872 A1 7/2004 Thompson
2004/0152622 A1 8/2004 Keith et al.
2004/0167464 A1 8/2004 Ireland et al.
2004/0167801 A1 8/2004 Say et al.
2004/0171921 A1 9/2004 Say et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2004/0176672 A1 9/2004 Silver et al.
2004/0186362 A1 9/2004 Brauker et al.
2004/0186365 A1 9/2004 Jin et al.
2004/0193020 A1 9/2004 Chiba et al.
2004/0193025 A1 9/2004 Steil et al.
2004/0193090 A1 9/2004 Lebel et al.
2004/0197846 A1 10/2004 Hockersmith et al.
2004/0199056 A1 10/2004 Husemann et al.
2004/0199059 A1 10/2004 Brauker et al.
2004/0204687 A1 10/2004 Mogensen et al.
2004/0204868 A1 10/2004 Maynard et al.
2004/0219664 A1 11/2004 Heller et al.
2004/0225338 A1 11/2004 Lebel et al.
2004/0236200 A1 11/2004 Say et al.
2004/0249253 A1 12/2004 Racchini et al.
2004/0254433 A1 12/2004 Bandis et al.
2004/0254434 A1 12/2004 Goodnow et al.
2004/0260478 A1 12/2004 Schwamm
2004/0267300 A1 12/2004 Mace
2005/0001024 A1 1/2005 Kusaka et al.
2005/0004439 A1 1/2005 Shin et al.
2005/0004494 A1 1/2005 Perez et al.
2005/0010269 A1 1/2005 Lebel et al.
2005/0017864 A1 1/2005 Tsoukalis
2005/0027177 A1 2/2005 Shin et al.
2005/0027180 A1 2/2005 Goode et al.
2005/0027181 A1 2/2005 Goode et al.
2005/0027462 A1 2/2005 Goode et al.
2005/0027463 A1 2/2005 Goode et al.
2005/0031689 A1 2/2005 Shults et al.
2005/0038332 A1 2/2005 Saidara et al.
2005/0043598 A1 2/2005 Goode, Jr. et al.
2005/0049179 A1 3/2005 Davidson et al.
2005/0070774 A1 3/2005 Addison et al.
2005/0070777 A1 3/2005 Cho et al.
2005/0090607 A1 4/2005 Tapsak et al.
2005/0096511 A1 5/2005 Fox et al.
2005/0096512 A1 5/2005 Fox et al.
2005/0096516 A1 5/2005 Soykan et al.
2005/0112169 A1 5/2005 Brauker et al.
2005/0113648 A1 5/2005 Yang et al.
2005/0113653 A1 5/2005 Fox et al.
2005/0113886 A1 5/2005 Fischell et al.
2005/0114068 A1 5/2005 Chey et al.
2005/0115832 A1 6/2005 Simpson et al.
2005/0116683 A1 6/2005 Cheng et al.
2005/0121322 A1 6/2005 Say et al.
2005/0131346 A1 6/2005 Douglas
2005/0134731 A1 6/2005 Lee et al.
2005/0137530 A1 6/2005 Campbell et al.
2005/0143635 A1 6/2005 Kamath et al.
2005/0154271 A1 7/2005 Rasdal et al.
2005/0176136 A1 8/2005 Burd et al.
2005/0177398 A1 8/2005 Watanabe et al.
2005/0182306 A1 8/2005 Sloan
2005/0187442 A1 8/2005 Cho et al.
2005/0187720 A1 8/2005 Goode, Jr. et al.
2005/0192494 A1 9/2005 Ginsberg
2005/0192557 A1 9/2005 Brauker et al.
2005/0195930 A1 9/2005 Spital et al.
2005/0199494 A1 9/2005 Say et al.
2005/0203360 A1 9/2005 Brauker et al.
2005/0204134 A1 9/2005 Von Arx et al.
2005/0214892 A1 9/2005 Kovatchev et al.
2005/0236361 A1 10/2005 Ufer et al.
2005/0239154 A1 10/2005 Feldman et al.
2005/0239156 A1 10/2005 Drucker et al.
2005/0241957 A1 11/2005 Mao et al.
2005/0245795 A1 11/2005 Goode, Jr. et al.
2005/0245799 A1 11/2005 Brauker et al.
2005/0245839 A1 11/2005 Stivoric et al.
2005/0245904 A1 11/2005 Estes et al.
2005/0251033 A1 11/2005 Scarantino et al.
2005/0272985 A1 12/2005 Kotulla et al.
2005/0277164 A1 12/2005 Drucker et al.
2005/0277912 A1 12/2005 John
2005/0287620 A1 12/2005 Heller et al.
2006/0001538 A1 1/2006 Kraft et al.
2006/0001551 A1 1/2006 Kraft et al.
2006/0004270 A1 1/2006 Bedard et al.
2006/0010098 A1 1/2006 Goodnow et al.
2006/0015020 A1 1/2006 Neale et al.
2006/0015024 A1 1/2006 Brister et al.
2006/0016700 A1 1/2006 Brister et al.
2006/0017923 A1 1/2006 Ruchti et al.
2006/0019327 A1 1/2006 Brister et al.
2006/0020186 A1 1/2006 Brister et al.
2006/0020187 A1 1/2006 Brister et al.
2006/0020188 A1 1/2006 Kamath et al.
2006/0020189 A1 1/2006 Brister et al.
2006/0020190 A1 1/2006 Kamath et al.
2006/0020191 A1 1/2006 Brister et al.
2006/0020192 A1 1/2006 Brister et al.
2006/0020300 A1 1/2006 Nghiem et al.
2006/0025663 A1 2/2006 Talbot et al.
2006/0029177 A1 2/2006 Cranford, Jr. et al.
2006/0031094 A1 2/2006 Cohen et al.
2006/0036139 A1 2/2006 Brister et al.
2006/0036140 A1 2/2006 Brister et al.
2006/0036141 A1 2/2006 Kamath et al.
2006/0036142 A1 2/2006 Brister et al.
2006/0036143 A1 2/2006 Brister et al.
2006/0036144 A1 2/2006 Brister et al.
2006/0036145 A1 2/2006 Brister et al.
2006/0058588 A1 3/2006 Zdeblick
2006/0079740 A1 4/2006 Silver et al.
2006/0091006 A1 5/2006 Wang et al.
2006/0142651 A1 6/2006 Brister et al.
2006/0154642 A1 7/2006 Scannell
2006/0155180 A1 7/2006 Brister et al.
2006/0156796 A1 7/2006 Burke et al.
2006/0166629 A1 7/2006 Reggiardo
2006/0173260 A1 8/2006 Gaoni et al.
2006/0173406 A1 8/2006 Hayes et al.
2006/0173444 A1 8/2006 Choy et al.
2006/0183984 A1 8/2006 Dobbles et al.
2006/0183985 A1 8/2006 Brister et al.
2006/0189863 A1 8/2006 Peyser et al.
2006/0193375 A1 8/2006 Lee et al.
2006/0202805 A1 9/2006 Schulman et al.
2006/0211072 A1 9/2006 Ryan et al.
2006/0222566 A1 10/2006 Brauker et al.
2006/0224109 A1 10/2006 Steil et al.
2006/0224141 A1 10/2006 Rush et al.
2006/0229512 A1 10/2006 Petisce et al.
2006/0247508 A1 11/2006 Fennell
2006/0247985 A1 11/2006 Liamos et al.
2006/0253296 A1 11/2006 Liisberg et al.
2006/0258929 A1 11/2006 Goode et al.
2006/0272652 A1 12/2006 Stocker et al.
2006/0281985 A1 12/2006 Ward et al.
2006/0290496 A1 12/2006 Peeters et al.
2006/0293607 A1 12/2006 Alt et al.
2007/0007133 A1 1/2007 Mang et al.
2007/0010950 A1 1/2007 Abensour et al.
2007/0016381 A1 1/2007 Kamath et al.
2007/0017983 A1 1/2007 Frank et al.
2007/0027381 A1 2/2007 Stafford
2007/0027507 A1 2/2007 Burdett et al.
2007/0032706 A1 2/2007 Kamath et al.
2007/0032717 A1 2/2007 Brister et al.
2007/0033074 A1 2/2007 Nitzan et al.
2007/0038044 A1 2/2007 Dobbles et al.
2007/0060803 A1 3/2007 Liljeryd et al.
2007/0060814 A1 3/2007 Stafford
2007/0060869 A1 3/2007 Tolle et al.
2007/0060979 A1 3/2007 Strother et al.
2007/0066873 A1 3/2007 Kamath et al.
2007/0066956 A1 3/2007 Finkel
2007/0071681 A1 3/2007 Gadkar et al.
2007/0073129 A1 3/2007 Shah et al.
2007/0078320 A1 4/2007 Stafford
2007/0078321 A1 4/2007 Mazza et al.
2007/0078322 A1 4/2007 Stafford

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0078323 A1 4/2007 Reggiardo et al.
2007/0078818 A1 4/2007 Zvitz et al.
2007/0093786 A1 4/2007 Goldsmith et al.
2007/0094216 A1 4/2007 Mathias et al.
2007/0100222 A1 5/2007 Mastrototaro et al.
2007/0106135 A1 5/2007 Sloan et al.
2007/0118405 A1 5/2007 Campbell et al.
2007/0124002 A1 5/2007 Estes et al.
2007/0149875 A1 6/2007 Ouyang et al.
2007/0153705 A1 7/2007 Rosar et al.
2007/0156094 A1 7/2007 Safabash et al.
2007/0163880 A1 7/2007 Woo et al.
2007/0168224 A1 7/2007 Letzt et al.
2007/0173706 A1 7/2007 Neinast et al.
2007/0173709 A1 7/2007 Petisce et al.
2007/0173710 A1 7/2007 Petisce et al.
2007/0173761 A1 7/2007 Kanderian et al.
2007/0179349 A1 8/2007 Hoyme et al.
2007/0179352 A1 8/2007 Randlov et al.
2007/0191701 A1 8/2007 Feldman et al.
2007/0191702 A1 8/2007 Yodfat et al.
2007/0203407 A1 8/2007 Hoss et al.
2007/0203966 A1 8/2007 Brauker et al.
2007/0208244 A1 9/2007 Brauker et al.
2007/0208246 A1* 9/2007 Brauker et al. 600/365
2007/0213657 A1 9/2007 Jennewine et al.
2007/0228071 A1 10/2007 Kamen et al.
2007/0232878 A1 10/2007 Kovatchev et al.
2007/0235331 A1 10/2007 Simpson et al.
2007/0249922 A1 10/2007 Peyser et al.
2007/0255321 A1 11/2007 Gerber et al.
2007/0255348 A1 11/2007 Holtzclaw
2007/0271285 A1 11/2007 Eichorn et al.
2007/0282299 A1 12/2007 Hellwig
2007/0299617 A1 12/2007 Willis
2008/0004515 A1 1/2008 Jennewine et al.
2008/0004601 A1 1/2008 Jennewine et al.
2008/0009692 A1 1/2008 Stafford
2008/0017522 A1 1/2008 Heller et al.
2008/0021436 A1 1/2008 Wolpert et al.
2008/0021666 A1 1/2008 Goode, Jr. et al.
2008/0029391 A1 2/2008 Mao et al.
2008/0033254 A1 2/2008 Kamath et al.
2008/0039702 A1 2/2008 Hayter et al.
2008/0045824 A1 2/2008 Tapsak et al.
2008/0057484 A1 3/2008 Miyata et al.
2008/0058625 A1 3/2008 McGarraugh et al.
2008/0058626 A1 3/2008 Miyata et al.
2008/0058678 A1 3/2008 Miyata et al.
2008/0058773 A1 3/2008 John
2008/0060955 A1 3/2008 Goodnow
2008/0061961 A1 3/2008 John
2008/0064937 A1 3/2008 McGarraugh et al.
2008/0071156 A1 3/2008 Brister et al.
2008/0071157 A1 3/2008 McGarraugh et al.
2008/0071158 A1 3/2008 McGarraugh et al.
2008/0081977 A1 4/2008 Hayter et al.
2008/0083617 A1 4/2008 Simpson et al.
2008/0086042 A1 4/2008 Brister et al.
2008/0086044 A1 4/2008 Brister et al.
2008/0086273 A1 4/2008 Shults et al.
2008/0092638 A1 4/2008 Brenneman et al.
2008/0097289 A1 4/2008 Steil et al.
2008/0108942 A1 5/2008 Brister et al.
2008/0114228 A1 5/2008 McCluskey et al.
2008/0139910 A1 6/2008 Mastrototaro et al.
2008/0154513 A1 6/2008 Kovatchev et al.
2008/0161666 A1 7/2008 Feldman et al.
2008/0167543 A1 7/2008 Say et al.
2008/0172205 A1 7/2008 Breton et al.
2008/0177149 A1 7/2008 Weinert et al.
2008/0177165 A1 7/2008 Blomquist et al.
2008/0182537 A1 7/2008 Manku et al.
2008/0183060 A1 7/2008 Steil et al.
2008/0183061 A1 7/2008 Goode et al.
2008/0183399 A1 7/2008 Goode et al.
2008/0188731 A1 8/2008 Brister et al.
2008/0188796 A1 8/2008 Steil et al.
2008/0189051 A1 8/2008 Goode et al.
2008/0194934 A1 8/2008 Ray et al.
2008/0194935 A1 8/2008 Brister et al.
2008/0194936 A1 8/2008 Goode et al.
2008/0194937 A1 8/2008 Goode et al.
2008/0194938 A1 8/2008 Brister et al.
2008/0195232 A1 8/2008 Carr-Brendel et al.
2008/0195967 A1 8/2008 Goode et al.
2008/0197024 A1 8/2008 Simpson et al.
2008/0200788 A1 8/2008 Brister et al.
2008/0200789 A1 8/2008 Brister et al.
2008/0200791 A1 8/2008 Simpson et al.
2008/0201325 A1 8/2008 Doniger et al.
2008/0208025 A1 8/2008 Shults et al.
2008/0208026 A1 8/2008 Noujaim et al.
2008/0208113 A1 8/2008 Damiano et al.
2008/0214900 A1 9/2008 Fennell et al.
2008/0214915 A1 9/2008 Brister et al.
2008/0214918 A1 9/2008 Brister et al.
2008/0228051 A1 9/2008 Shults et al.
2008/0228054 A1 9/2008 Shults et al.
2008/0228055 A1 9/2008 Sher
2008/0234663 A1 9/2008 Yodfat et al.
2008/0234943 A1 9/2008 Ray et al.
2008/0242961 A1 10/2008 Brister et al.
2008/0242963 A1 10/2008 Essenpreis et al.
2008/0254544 A1 10/2008 Modzelewski et al.
2008/0255434 A1 10/2008 Hayter et al.
2008/0255437 A1 10/2008 Hayter
2008/0255808 A1 10/2008 Hayter
2008/0256048 A1 10/2008 Hayter
2008/0262469 A1 10/2008 Brister et al.
2008/0269714 A1 10/2008 Mastrototaro et al.
2008/0269723 A1 10/2008 Mastrototaro et al.
2008/0275313 A1 11/2008 Brister et al.
2008/0287761 A1 11/2008 Hayter
2008/0287762 A1 11/2008 Hayter
2008/0287763 A1 11/2008 Hayter
2008/0287764 A1 11/2008 Rasdal et al.
2008/0287765 A1 11/2008 Rasdal et al.
2008/0287766 A1 11/2008 Rasdal et al.
2008/0288180 A1 11/2008 Hayter
2008/0288204 A1 11/2008 Hayter et al.
2008/0294024 A1 11/2008 Cosentino et al.
2008/0296155 A1 12/2008 Shults et al.
2008/0300572 A1 12/2008 Rankers et al.
2008/0306368 A1 12/2008 Goode et al.
2008/0306434 A1 12/2008 Dobbles et al.
2008/0306435 A1 12/2008 Kamath et al.
2008/0306444 A1 12/2008 Brister et al.
2008/0312841 A1 12/2008 Hayter
2008/0312842 A1 12/2008 Hayter
2008/0312844 A1 12/2008 Hayter et al.
2008/0312845 A1 12/2008 Hayter et al.
2008/0314395 A1 12/2008 Kovatchev et al.
2008/0319085 A1 12/2008 Wright et al.
2008/0319279 A1 12/2008 Ramsay et al.
2008/0319295 A1 12/2008 Bernstein et al.
2008/0319296 A1 12/2008 Bernstein et al.
2009/0005665 A1 1/2009 Hayter et al.
2009/0005666 A1 1/2009 Shin et al.
2009/0005729 A1 1/2009 Hendrixson et al.
2009/0006034 A1 1/2009 Hayter et al.
2009/0006061 A1 1/2009 Thukral et al.
2009/0006133 A1 1/2009 Weinert et al.
2009/0012376 A1 1/2009 Agus
2009/0012379 A1 1/2009 Goode et al.
2009/0018424 A1 1/2009 Kamath et al.
2009/0018425 A1 1/2009 Ouyang et al.
2009/0030293 A1 1/2009 Cooper et al.
2009/0030294 A1 1/2009 Petisce et al.
2009/0033482 A1 2/2009 Hayter et al.
2009/0036747 A1 2/2009 Hayter et al.
2009/0036758 A1 2/2009 Brauker et al.
2009/0036760 A1 2/2009 Hayter
2009/0036763 A1 2/2009 Brauker et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2009/0040022 A1 2/2009 Finkenzeller
2009/0043181 A1 2/2009 Brauker et al.
2009/0043182 A1 2/2009 Brauker et al.
2009/0043525 A1 2/2009 Brauker et al.
2009/0043541 A1 2/2009 Brauker et al.
2009/0043542 A1 2/2009 Brauker et al.
2009/0045055 A1 2/2009 Rhodes et al.
2009/0048503 A1 2/2009 Dalal et al.
2009/0054745 A1 2/2009 Jennewine et al.
2009/0054747 A1 2/2009 Fennell
2009/0054748 A1 2/2009 Feldman et al.
2009/0055149 A1 2/2009 Hayter et al.
2009/0062633 A1 3/2009 Brauker et al.
2009/0062635 A1 3/2009 Brauker et al.
2009/0062767 A1 3/2009 VanAntwerp et al.
2009/0063402 A1 3/2009 Hayter
2009/0076356 A1 3/2009 Simpson et al.
2009/0076360 A1 3/2009 Brister et al.
2009/0076361 A1 3/2009 Kamath et al.
2009/0082693 A1 3/2009 Stafford
2009/0085873 A1 4/2009 Betts et al.
2009/0088614 A1 4/2009 Taub et al.
2009/0093687 A1 4/2009 Telfort et al.
2009/0099436 A1 4/2009 Brister et al.
2009/0105560 A1 4/2009 Solomon
2009/0105570 A1 4/2009 Sloan et al.
2009/0105571 A1 4/2009 Fennell et al.
2009/0105636 A1 4/2009 Hayter et al.
2009/0124877 A1 5/2009 Goode et al.
2009/0124878 A1 5/2009 Goode et al.
2009/0124879 A1 5/2009 Brister et al.
2009/0124964 A1 5/2009 Leach et al.
2009/0131768 A1 5/2009 Simpson et al.
2009/0131769 A1 5/2009 Leach et al.
2009/0131776 A1 5/2009 Simpson et al.
2009/0131777 A1 5/2009 Simpson et al.
2009/0137886 A1 5/2009 Shariati et al.
2009/0137887 A1 5/2009 Shariati et al.
2009/0143659 A1 6/2009 Li et al.
2009/0143660 A1 6/2009 Brister et al.
2009/0156919 A1 6/2009 Brister et al.
2009/0156924 A1 6/2009 Shariati et al.
2009/0163790 A1 6/2009 Brister et al.
2009/0163791 A1 6/2009 Brister et al.
2009/0164190 A1 6/2009 Hayter
2009/0164239 A1 6/2009 Hayter et al.
2009/0164251 A1 6/2009 Hayter
2009/0177068 A1 7/2009 Stivoric et al.
2009/0178459 A1 7/2009 Li et al.
2009/0182217 A1 7/2009 Li et al.
2009/0192366 A1 7/2009 Mensinger et al.
2009/0192380 A1 7/2009 Shariati et al.
2009/0192722 A1 7/2009 Shariati et al.
2009/0192724 A1 7/2009 Brauker et al.
2009/0192745 A1 7/2009 Kamath et al.
2009/0192751 A1 7/2009 Kamath et al.
2009/0198118 A1 8/2009 Hayter et al.
2009/0203981 A1 8/2009 Brauker et al.
2009/0204341 A1 8/2009 Brauker et al.
2009/0216100 A1 8/2009 Ebner et al.
2009/0216103 A1 8/2009 Brister et al.
2009/0227855 A1 9/2009 Hill et al.
2009/0240120 A1 9/2009 Mensinger et al.
2009/0240128 A1 9/2009 Mensinger et al.
2009/0240193 A1 9/2009 Mensinger et al.
2009/0240440 A1 9/2009 Shurabura et al.
2009/0242399 A1 10/2009 Kamath et al.
2009/0242425 A1 10/2009 Kamath et al.
2009/0247855 A1 10/2009 Boock et al.
2009/0247856 A1 10/2009 Boock et al.
2009/0247931 A1 10/2009 Damgaard-Sorensen
2009/0253973 A1 10/2009 Bashan et al.
2009/0287073 A1 11/2009 Boock et al.
2009/0287074 A1 11/2009 Shults et al.
2009/0292188 A1 11/2009 Hoss et al.
2009/0298182 A1 12/2009 Schulat et al.
2009/0299155 A1 12/2009 Yang et al.
2009/0299156 A1 12/2009 Simpson et al.
2009/0299162 A1 12/2009 Brauker et al.
2009/0299276 A1 12/2009 Brauker et al.
2010/0010324 A1 1/2010 Brauker et al.
2010/0010329 A1 1/2010 Taub et al.
2010/0010331 A1 1/2010 Brauker et al.
2010/0010332 A1 1/2010 Brauker et al.
2010/0016687 A1 1/2010 Brauker et al.
2010/0016698 A1 1/2010 Rasdal et al.
2010/0022855 A1 1/2010 Brauker et al.
2010/0030038 A1 2/2010 Brauker et al.
2010/0030053 A1 2/2010 Goode, Jr. et al.
2010/0030484 A1 2/2010 Brauker et al.
2010/0030485 A1 2/2010 Brauker et al.
2010/0036215 A1 2/2010 Goode, Jr. et al.
2010/0036216 A1 2/2010 Goode, Jr. et al.
2010/0036222 A1 2/2010 Goode, Jr. et al.
2010/0036223 A1 2/2010 Goode, Jr. et al.
2010/0036225 A1 2/2010 Goode, Jr. et al.
2010/0041971 A1 2/2010 Goode, Jr. et al.
2010/0045465 A1 2/2010 Brauker et al.
2010/0049024 A1 2/2010 Saint et al.
2010/0057040 A1 3/2010 Hayter
2010/0057041 A1 3/2010 Hayter
2010/0057042 A1 3/2010 Hayter
2010/0057044 A1 3/2010 Hayter
2010/0057057 A1 3/2010 Hayter et al.
2010/0063373 A1 3/2010 Kamath et al.
2010/0076283 A1 3/2010 Simpson et al.
2010/0081906 A1 4/2010 Hayter et al.
2010/0081908 A1 4/2010 Dobbles et al.
2010/0081910 A1 4/2010 Brister et al.
2010/0087724 A1 4/2010 Brauker et al.
2010/0096259 A1 4/2010 Zhang et al.
2010/0099970 A1 4/2010 Shults et al.
2010/0099971 A1 4/2010 Shults et al.
2010/0105999 A1 4/2010 Dixon et al.
2010/0119693 A1 5/2010 Tapsak et al.
2010/0121167 A1 5/2010 McGarraugh et al.
2010/0121169 A1 5/2010 Petisce et al.
2010/0141656 A1 6/2010 Krieftewirth
2010/0152554 A1 6/2010 Steine et al.
2010/0160759 A1 6/2010 Celentano et al.
2010/0168538 A1 7/2010 Keenan et al.
2010/0168546 A1 7/2010 Kamath et al.
2010/0174266 A1 7/2010 Estes
2010/0185175 A1 7/2010 Kamen et al.
2010/0191082 A1 7/2010 Brister et al.
2010/0198034 A1 8/2010 Thomas et al.
2010/0204557 A1 8/2010 Kiaie et al.
2010/0213080 A1 8/2010 Celentano et al.
2010/0240975 A1 9/2010 Goode et al.
2010/0274111 A1 10/2010 Say et al.
2010/0312176 A1 12/2010 Lauer et al.
2010/0313105 A1 12/2010 Nekoomaram et al.
2011/0024043 A1 2/2011 Boock et al.
2011/0024307 A1 2/2011 Simpson et al.
2011/0027127 A1 2/2011 Simpson et al.
2011/0027453 A1 2/2011 Boock et al.
2011/0027458 A1 2/2011 Boock et al.
2011/0028815 A1 2/2011 Simpson et al.
2011/0028816 A1 2/2011 Simpson et al.
2011/0031986 A1 2/2011 Bhat et al.
2011/0077490 A1 3/2011 Simpson et al.
2011/0112696 A1 5/2011 Yodfat et al.
2011/0148905 A1 6/2011 Simmons et al.
2011/0208027 A1 8/2011 Wagner et al.
2011/0213225 A1 9/2011 Bernstein et al.
2011/0257895 A1 10/2011 Brauker et al.
2011/0287528 A1 11/2011 Fern et al.
2011/0289497 A1 11/2011 Kiaie et al.
2011/0320130 A1 12/2011 Valdes et al.
2012/0078071 A1 3/2012 Bohm et al.
2012/0108934 A1 5/2012 Valdes et al.
2012/0165626 A1 6/2012 Irina et al.
2012/0165640 A1 6/2012 Galley et al.
2012/0173200 A1 7/2012 Breton et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0190989	A1	7/2012	Kaiser et al.
2013/0035575	A1	2/2013	Mayou et al.
2014/0121480	A1	5/2014	Budiman et al.

FOREIGN PATENT DOCUMENTS

EP	0127958	12/1984
EP	0320109	6/1989
EP	0353328	2/1990
EP	0390390	10/1990
EP	0396788	11/1990
EP	0286118	1/1995
EP	1048264	11/2000
WO	WO-93/06237	4/1993
WO	WO-96/25089	8/1996
WO	WO-96/35370	11/1996
WO	WO-98/35053	8/1998
WO	WO-99/56613	11/1999
WO	WO-00/49940	8/2000
WO	WO-00/59370	10/2000
WO	WO-00/78992	12/2000
WO	WO-01/52935	7/2001
WO	WO-01/54753	8/2001
WO	WO-02/16905	2/2002
WO	WO-02/058537	8/2002
WO	WO-03/076893	9/2003
WO	WO-03/082091	10/2003
WO	WO-03/085372	10/2003
WO	WO-2004/047445	6/2004
WO	WO-2004/061420	7/2004
WO	WO-2005/010756	2/2005
WO	WO-2005/040404	5/2005
WO	WO-2005/041766	5/2005
WO	WO-2005/089103	9/2005
WO	WO-2005/119238	12/2005
WO	WO-2006/024671	3/2006
WO	WO-2006/051466	5/2006
WO	WO-2006/064397	6/2006
WO	WO-2006/079114	7/2006
WO	WO-2006/118947	11/2006
WO	WO-2007/007459	1/2007
WO	WO-2007/016399	2/2007
WO	WO-2007/027788	3/2007
WO	WO-2007/041069	4/2007
WO	WO-2007/041070	4/2007
WO	WO-2007/041248	4/2007
WO	WO-2007/056638	5/2007
WO	WO-2007/097754	8/2007
WO	WO-2007/101223	9/2007
WO	WO-2007/120363	10/2007
WO	WO-2007/126444	11/2007
WO	WO-2007/053832	12/2007
WO	WO-2007/143225	12/2007
WO	WO-2008/021913	2/2008
WO	WO-2008/042760	4/2008
WO	WO-2008/128210	10/2008
WO	WO-2008/130896	10/2008
WO	WO-2008/130897	10/2008
WO	WO-2008/130898	10/2008
WO	WO-2008/143943	11/2008
WO	WO-2009/018058	2/2009
WO	WO-2009/086216	7/2009
WO	WO-2009/096992	8/2009
WO	WO-2009/097594	8/2009
WO	WO-2010/077329	7/2010

OTHER PUBLICATIONS

Aussedat, B., et al., "A User-Friendly Method for Calibrating a Subcutaneous Glucose Sensor-Based Hypoglycemic Alarm", *Biosensors & Bioelectronics*, vol. 12, No. 11, 1997, pp. 1061-1070.

Bennion, N., et al., "Alternate Site Glucose Testing: A Crossover Design", *Diabetes Technology & Therapeutics*, vol. 4, No. 1, 2002, pp. 25-33.

Blank, T. B., et al., "Clinical Results From a Non-Invasive Blood Glucose Monitor", *Optical Diagnostics and Sensing of Biological Fluids and Glucose and Cholesterol Monitoring II, Proceedings of SPIE*, vol. 4624, 2002, pp. 1-10.

Bremer, T. M., et al., "Benchmark Data from the Literature for Evaluation of New Glucose Sensing Technologies", *Diabetes Technology & Therapeutics*, vol. 3, No. 3, 2001, pp. 409-418.

Brooks, S. L., et al., "Development of an On-Line Glucose Sensor for Fermentation Monitoring", *Biosensors*, vol. 3, 1987/88, pp. 45-56.

Cass, A. E., et al., "Ferrocene-Medicated Enzyme Electrode for Amperometric Determination of Glucose", *Analytical Chemistry*, vol. 56, No. 4, 1984, 667-671.

Cheyne, E. H., et al., "Performance of a Continuous Glucose Monitoring System During Controlled Hypoglycaemia in Healthy Volunteers", *Diabetes Technology & Therapeutics*, vol. 4, No. 5, 2002, pp. 607-613.

Csoregi, E., et al., "Design and Optimization of a Selective Subcutaneously Implantable Glucose Electrode Based on 'Wired' Glucose Oxidase", *Analytical Chemistry*, vol. 67, No. 7, 1995, pp. 1240-1244.

El-Khatib, F. H, et al., "Adaptive Closed-Loop Control Provides Blood-Glucose Regulation Using Subcutaneous Insulin and Glucagon Infusion in Diabetic Swine", *Journal of Diabetes Science and Technology*, vol. 1, No. 2, 2007, pp. 181-192.

Feldman, B., et al., "A Continuous Glucose Sensor Based on Wired Enzyme™ Technology—Results from a 3-Day Trial in Patients with Type 1 Diabetes", *Diabetes Technology & Therapeutics*, vol. 5, No. 5, 2003, pp. 769-779.

Feldman, B., et al., "Correlation of Glucose Concentrations in Interstitial Fluid and Venous Blood During Periods of Rapid Glucose Change", *Abbott Diabetes Care, Inc. Freestyle Navigator Continuous Glucose Monitor Pamphlet*, 2004.

Garg, S., et al., "Improvement in Glycemic Excursions with a Transcutaneous, Real-Time Continuous Glucose Sensor", *Diabetes Care*, vol. 29, No. 1, 2006, pp. 44-50.

Isermann, R., "Supervision, Fault-Detection and Fault-Diagnosis Methods—An Introduction", *Control Engineering Practice*, vol. 5, No. 5, 1997, pp. 639-652.

Isermann, R., et al., "Trends in the Application of Model-Based Fault Detection and Diagnosis of Technical Processes", *Control Engineering Practice*, vol. 5, No. 5, 1997, pp. 709-719.

Johnson, P. C., "Peripheral Circulation", *John Wiley & Sons*, 1978, pp. 198.

Jungheim, K., et al., "How Rapid Does Glucose Concentration Change in Daily Life of Patients with Type 1 Diabetes?", 2002, pp. 250.

Jungheim, K., et al., "Risky Delay of Hypoglycemia Detection by Glucose Monitoring at the Arm", *Diabetes Care*, vol. 24, No. 7, 2001, pp. 1303-1304.

Kaplan, S. M., "Wiley Electrical and Electronics Engineering Dictionary", *IEEE Press*, 2004, pp. 141, 142, 548, 549.

Kuure-Kinsey, M., et al., "A Dual-Rate Kalman Filter for Continuous Glucose Monitoring", *Proceedings of the 28th IEEE, EMBS Annual International Conference*, New York City, 2006, pp. 63-66.

Lo, B., et al., "Key Technical Challenges and Current Implementations of Body Sensor Networks", *Body Sensor Networks*, 2005, pp. 1-5.

Lodwig, V., et al., "Continuous Glucose Monitoring with Glucose Sensors: Calibration and Assessment Criteria", *Diabetes Technology & Therapeutics*, vol. 5, No. 4, 2003, pp. 573-587.

Lortz, J., et al., "What is Bluetooth? We Explain the Newest Short-Range Connectivity Technology", *Smart Computing Learning Series, Wireless Computing*, vol. 8, Issue 5, 2002, pp. 72-74.

Malin, S. F., et al., "Noninvasive Prediction of Glucose by Near-Infrared Diffuse Reflectance Spectroscopy", *Clinical Chemistry*, vol. 45, No. 9, 1999, pp. 1651-1658.

McGarraugh, G., et al., "Glucose Measurements Using Blood Extracted from the Forearm and the Finger", *TheraSense, Inc.*, 2001, 16 Pages.

McGarraugh, G., et al., "Physiological Influences on Off-Finger Glucose Testing", *Diabetes Technology & Therapeutics*, vol. 3, No. 3, 2001, pp. 367-376.

(56) **References Cited**

OTHER PUBLICATIONS

McKean, B. D., et al., "A Telemetry-Instrumentation System for Chronically Implanted Glucose and Oxygen Sensors", *IEEE Transactions on Biomedical Engineering*, vol. 35, No. 7, 1988, pp. 526-532.

Morbiducci, U, et al., "Improved Usability of the Minimal Model of Insulin Sensitivity Based on an Automated Approach and Genetic Algorithms for Parameter Estimation", *Clinical Science*, vol. 112, 2007, pp. 257-263.

Mougiakakou, et al., "A Real Time Simulation Model of Glucose-Insulin Metabolism for Type 1 Diabetes Patients", *Proceedings of the 2005 IEEE*, 2005, pp. 298-301.

Panteleon, A. E., et al., "The Role of the Independent Variable to Glucose Sensor Calibration", *Diabetes Technology & Therapeutics*, vol. 5, No. 3, 2003, pp. 401-410.

Parker, R., et al., "Robust H∞ Glucose Control in Diabetes Using a Physiological Model", *AIChE Journal*, vol. 46, No. 12, 2000, pp. 2537-2549.

Pickup, J., et al., "Implantable Glucose Sensors: Choosing the Appropriate Sensing Strategy", *Biosensors*, vol. 3, 1987/88, pp. 335-346.

Pickup, J., et al., "In Vivo Molecular Sensing in Diabetes Mellitus: An Implantable Glucose Sensor with Direct Electron Transfer", *Diabetologia*, vol. 32, 1989, pp. 213-217.

Pishko, M. V., et al., "Amperometric Glucose Microelectrodes Prepared Through Immobilization of Glucose Oxidase in Redox Hydrogels", *Analytical Chemistry*, vol. 63, No. 20, 1991, pp. 2268-2272.

Quinn, C. P., et al., "Kinetics of Glucose Delivery to Subcutaneous Tissue in Rats Measured with 0.3-mm Amperometric Microsensors", *The American Physiological Society*, 1995, E155-E161.

Rodriguez, N., et al., "Flexible Communication and Control Protocol for Injectable Neuromuscular Interfaces", *IEEE Transactions on Biomedical Circuits and Systems*, vol. 1, No. 1, 2007, pp. 19-27.

Roe, J. N., et al., "Bloodless Glucose Measurements", *Critical Review in Therapeutic Drug Carrier Systems*, vol. 15, Issue 3, 1998, pp. 199-241.

Sakakida, M., et al., "Development of Ferrocene-Mediated Needle-Type Glucose Sensor as a Measure of True Subcutaneous Tissue Glucose Concentrations", *Artificial Organs Today*, vol. 2, No. 2, 1992, pp. 145-158.

Sakakida, M., et al., "Ferrocene-Mediated Needle-Type Glucose Sensor Covered with Newly Designed Biocompatible Membrane", *Sensors and Actuators B*, vol. 13-14, 1993, pp. 319-322.

Salehi, C., et al., "A Telemetry-Instrumentation System for Long-Term Implantable Glucose and Oxygen Sensors", *Analytical Letters*, vol. 29, No. 13, 1996, pp. 2289-2308.

Schmidtke, D. W., et al., "Measurement and Modeling of the Transient Difference Between Blood and Subcutaneous Glucose Concentrations in the Rat After Injection of Insulin", *Proceedings of the National Academy of Sciences*, vol. 95, 1998, pp. 294-299.

Shaw, G. W., et al., "In Vitro Testing of a Simply Constructed, Highly Stable Glucose Sensor Suitable for Implantation in Diabetic Patients", *Biosensors & Bioelectronics*, vol. 6, 1991, pp. 401-406.

Shichiri, M., et al., "Glycaemic Control in Pancreatectomized Dogs with a Wearable Artificial Endocrine Pancreas", *Diabetologia*, vol. 24, 1983, pp. 179-184.

Shichiri, M., et al., "In Vivo Characteristics of Needle-Type Glucose Sensor—Measurements of Subcutaneous Glucose Concentrations in Human Volunteers", *Hormone and Metabolic Research Supplement Series*, vol. 20, 1988, pp. 17-20.

Shichiri, M., et al., "Membrane Design for Extending the Long-Life of an Implantable Glucose Sensor", *Diabetes Nutrition and Metabolism*, vol. 2, 1989, pp. 309-313.

Shichiri, M., et al., "Needle-type Glucose Sensor for Wearable Artificial Endocrine Pancreas", *Implantable Sensors for Closed-Loop Prosthetic Systems, Chapter 15*, 1985, pp. 197-210.

Shichiri, M., et al., "Telemetry Glucose Monitoring Device With Needle-Type Glucose Sensor: A Useful Tool for Blood Glucose Monitoring in Diabetic Individuals", *Diabetes Care*, vol. 9, No. 3, 1986, pp. 298-301.

Shichiri, M., et al., "Wearable Artificial Endocrine Pancreas With Needle-Type Glucose Sensor", *The Lancet*, 1982, pp. 1129-1131.

Shults, M. C., et al., "A Telemetry-Instrumentation System for Monitoring Multiple Subcutaneously Implanted Glucose Sensors", *IEEE Transactions on Biomedical Engineering*, vol. 41, No. 10, 1994, pp. 937-942.

Sternberg, R., et al., "Study and Development of Multilayer Needle-Type Enzyme-Based Glucose Microsensors", *Biosensors*, vol. 4, 1988, pp. 27-40.

Thompson, M., et al., "In Vivo Probes: Problems and Perspectives", *Clinical Biochemistry*, vol. 19, 1986, pp. 255-261.

Turner, A., et al., "Diabetes Mellitus: Biosensors for Research and Management", *Biosensors*, vol. 1, 1985, pp. 85-115.

Updike, S. J., et al., "Principles of Long-Term Fully Implanted Sensors with Emphasis on Radiotelemetric Monitoring of Blood Glucose from Inside a Subcutaneous Foreign Body Capsule (FBC)", *Biosensors in the Body: Continuous in vivo Monitoring, Chapter 4*, 1997, pp. 117-137.

Velho, G., et al., "Strategies for Calibrating a Subcutaneous Glucose Sensor", *Biomedica Biochimica Acta*, vol. 48, 1989, pp. 957-964.

Wilson, G. S., et al., "Progress Toward the Development of an Implantable Sensor for Glucose", *Clinical Chemistry*, vol. 38, No. 9, 1992, pp. 1613-1617.

U.S. Appl. No. 12/257,356, Notice of Allowance mailed Dec. 10, 2012.

U.S. Appl. No. 12/257,356, Office Action mailed Jul. 16, 2012.

U.S. Appl. No. 12/257,356, Office Action mailed Nov. 25, 2011.

U.S. Appl. No. 12/257,356, Office Action mailed Sep. 26, 2012.

U.S. Appl. No. 12/363,706, Advisory Action mailed Jan. 30, 2013.

U.S. Appl. No. 12/363,706, Notice of Allowance mailed Mar. 7, 2013.

U.S. Appl. No. 12/363,706, Office Action mailed Jan. 23, 2012.

U.S. Appl. No. 12/363,706, Office Action mailed Jun. 25, 2012.

U.S. Appl. No. 12/363,706, Office Action mailed Oct. 11, 2012.

Arnold, M. A., et al., "Selectivity Assessment of Noninvasive Glucose Measurements Based on Analysis of Multivariate Calibration Vectors", *Journal of Diabetes Science and Technology*, vol. 1, No. 4, 2007, pp. 454-462.

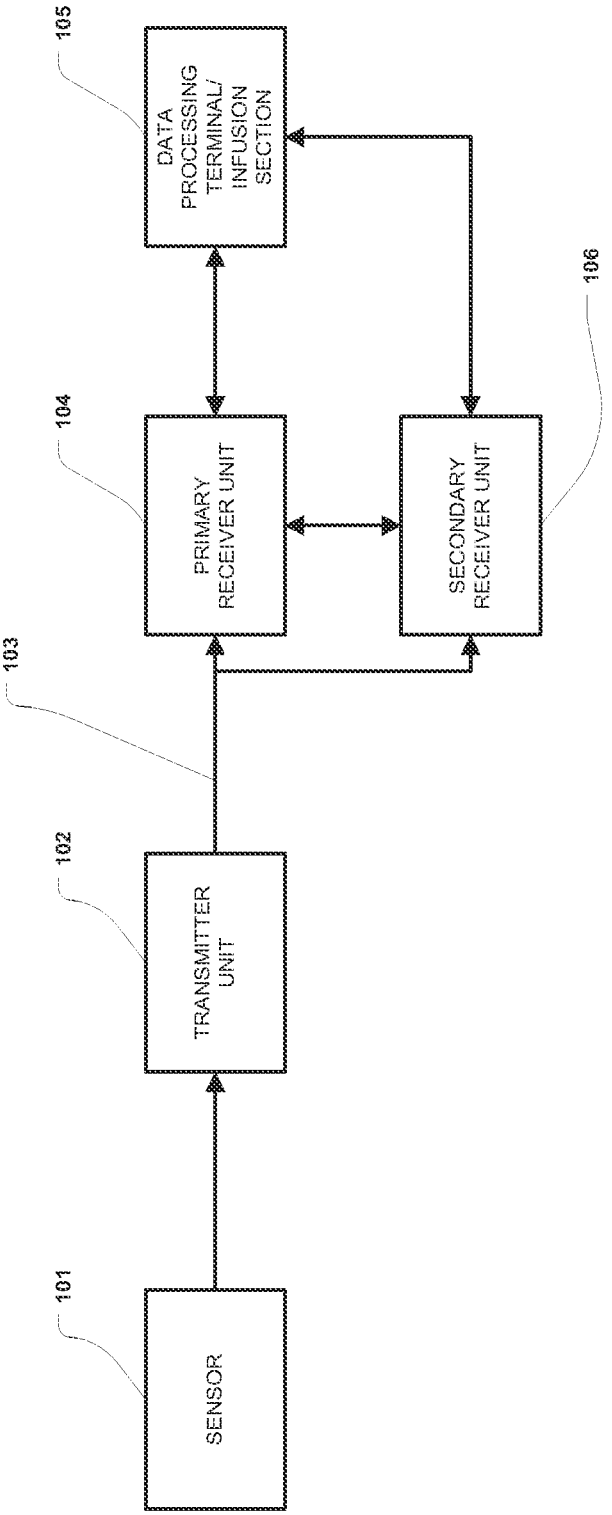
Boyne, M. S., et al., "Timing of Changes in Interstitial and Venous Blood Glucose Measured With a Continuous Subcutaneous Glucose Sensor", *Diabetes*, vol. 52, Nov. 2003, pp. 2790-2794.

Eren-Oruklu, M., et al., "Estimation of Future Glucose Concentrations with Subject-Specific Recursive Linear Models", *Diabetes Technology & Therapeutics* vol. 11(4), 2009, pp. 243-253.

Li, Y., et al., "In Vivo Release From a Drug Delivery MEMS Device", *Journal of Controlled Release*, vol. 100, 2004, pp. 211-219.

U.S. Appl. No. 13/763,518, Office Action mailed Jun. 25, 2015.

* cited by examiner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DATA PROCESSING TERMINAL/ INFUSION SECTION
104
PRIMARY RECEIVER UNIT
106
SECONDARY RECEIVER UNIT
103
102
TRANSMITTER UNIT
101
SENSOR

100

FIGURE 1

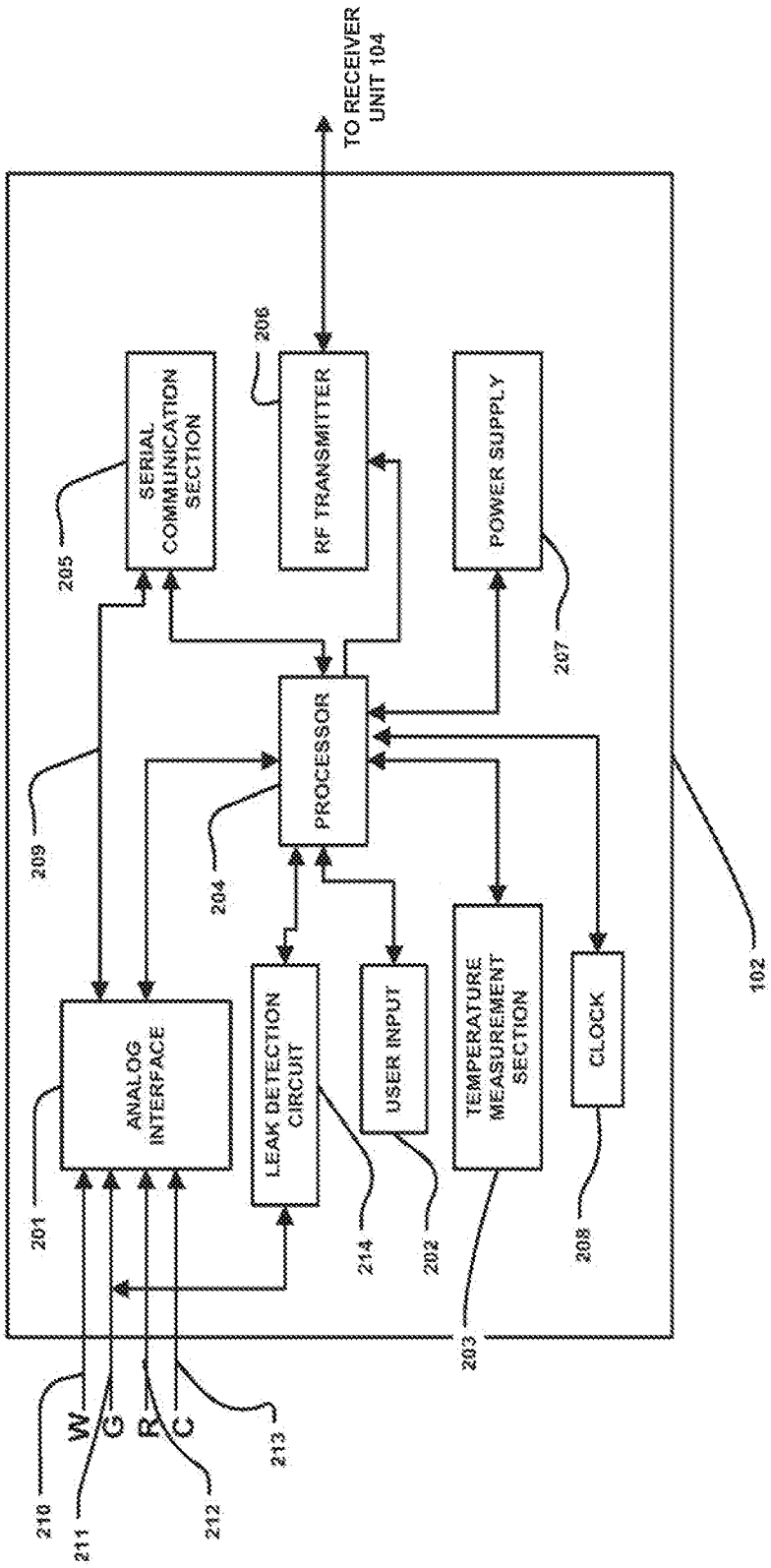
TO RECEIVER UNIT 104
206
SERIAL COMMUNICATION SECTION
RF TRANSMITTER
POWER SUPPLY
205
207
PROCESSOR
209
204
ANALOG INTERFACE
LEAK DETECTION CIRCUIT
USER INPUT
TEMPERATURE MEASUREMENT SECTION
CLOCK
102
201
214
202
208
203
W
G
R
C
210
211
212
213

FIGURE 2

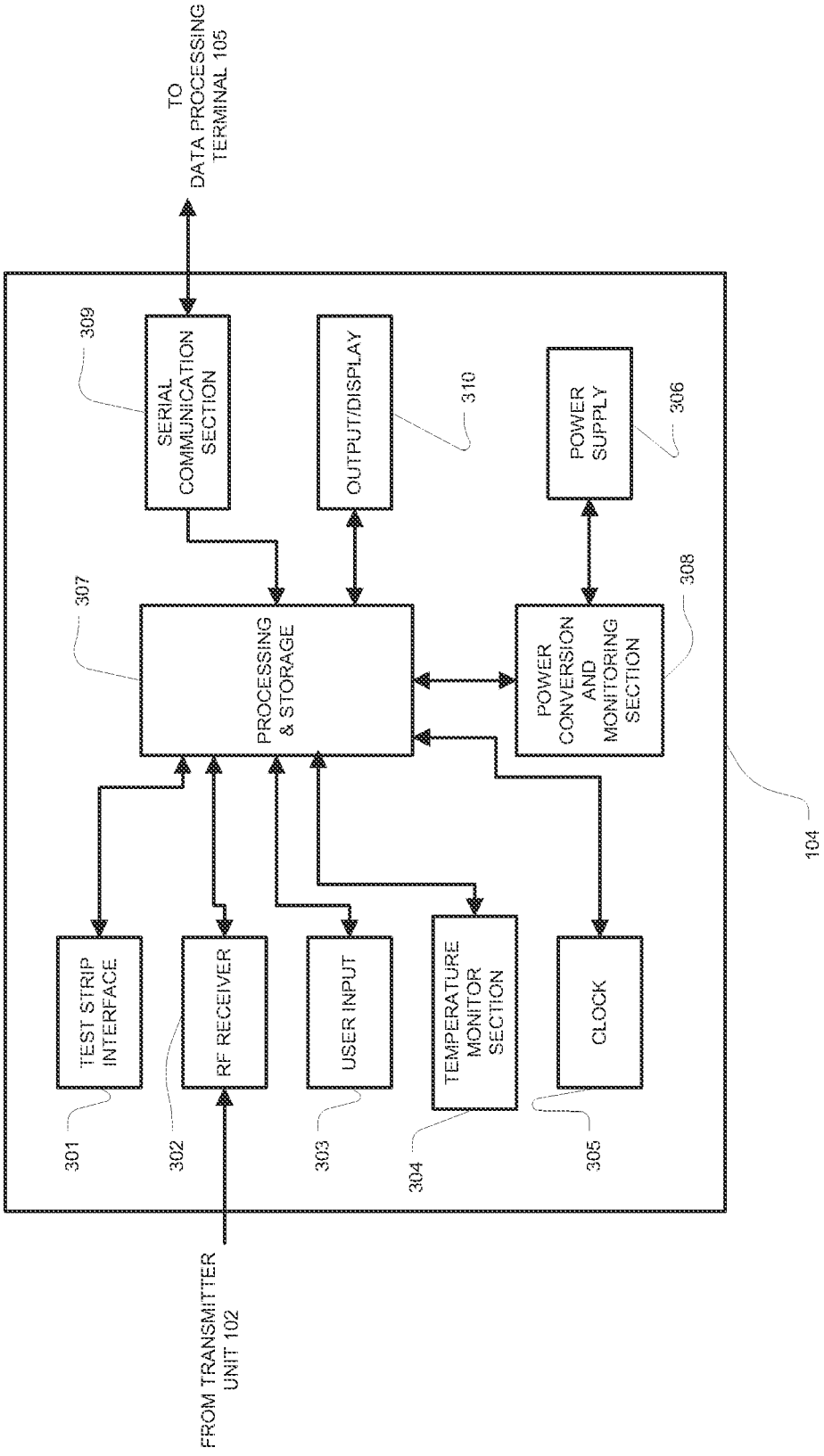
TO DATA PROCESSING TERMINAL 105
309
SERIAL COMMUNICATION SECTION
OUTPUT/DISPLAY
310
POWER SUPPLY
306
307
PROCESSING & STORAGE
POWER CONVERSION AND MONITORING SECTION
308
TEST STRIP INTERFACE
RF RECEIVER
USER INPUT
TEMPERATURE MONITOR SECTION
CLOCK
301
302
303
304
305
104
FROM TRANSMITTER UNIT 102

FIGURE 3

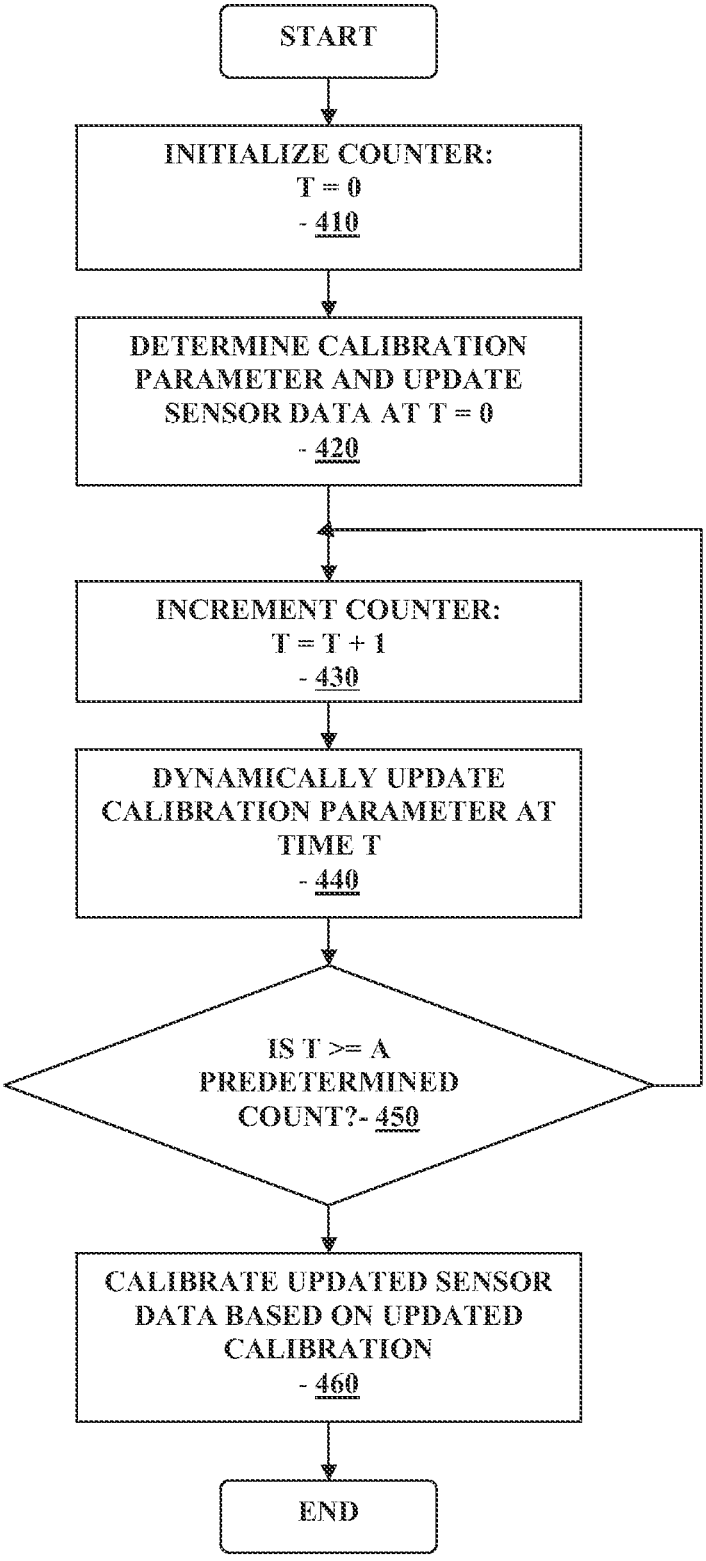
START
INITIALIZE COUNTER:
T = 0
- 410
DETERMINE CALIBRATION PARAMETER AND UPDATE SENSOR DATA AT T = 0
- 420
INCREMENT COUNTER:
T = T + 1
- 430
DYNAMICALLY UPDATE CALIBRATION PARAMETER AT TIME T
- 440
IS T >= A PREDETERMINED COUNT?- 450
CALIBRATE UPDATED SENSOR DATA BASED ON UPDATED CALIBRATION
- 460
END

FIGURE 4

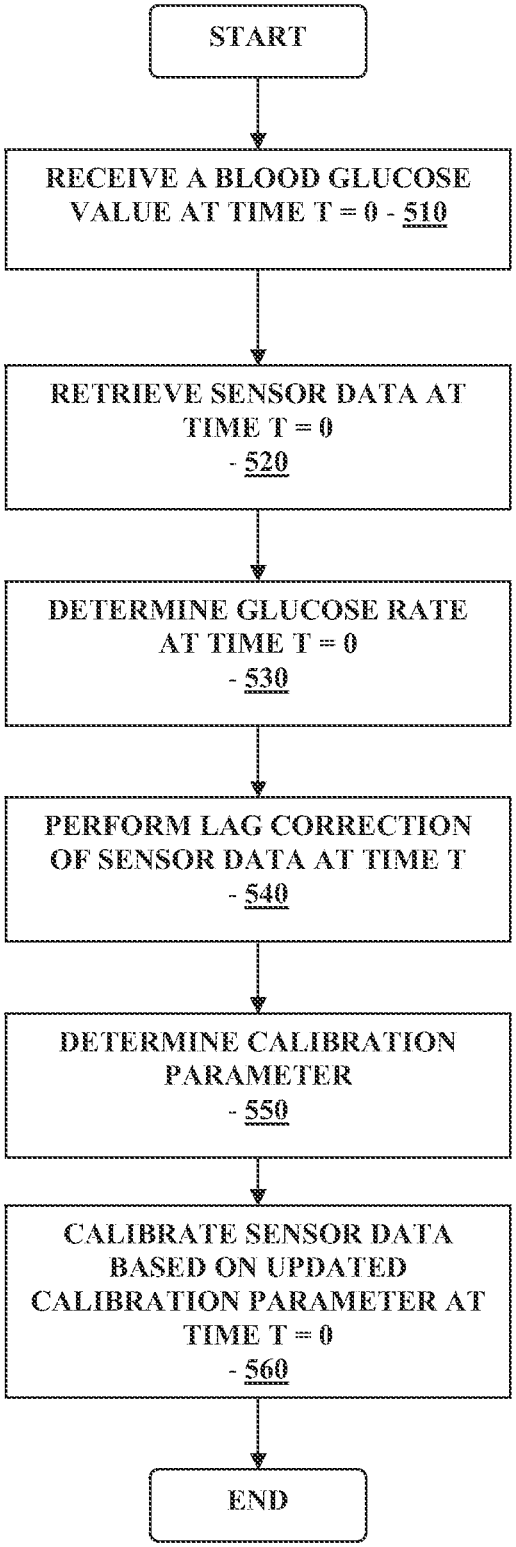
START
RECEIVE A BLOOD GLUCOSE VALUE AT TIME T = 0 - 510
RETRIEVE SENSOR DATA AT TIME T = 0 - 520
DETERMINE GLUCOSE RATE AT TIME T = 0 - 530
PERFORM LAG CORRECTION OF SENSOR DATA AT TIME T - 540
DETERMINE CALIBRATION PARAMETER - 550
CALIBRATE SENSOR DATA BASED ON UPDATED CALIBRATION PARAMETER AT TIME T = 0 - 560
END

FIGURE 5

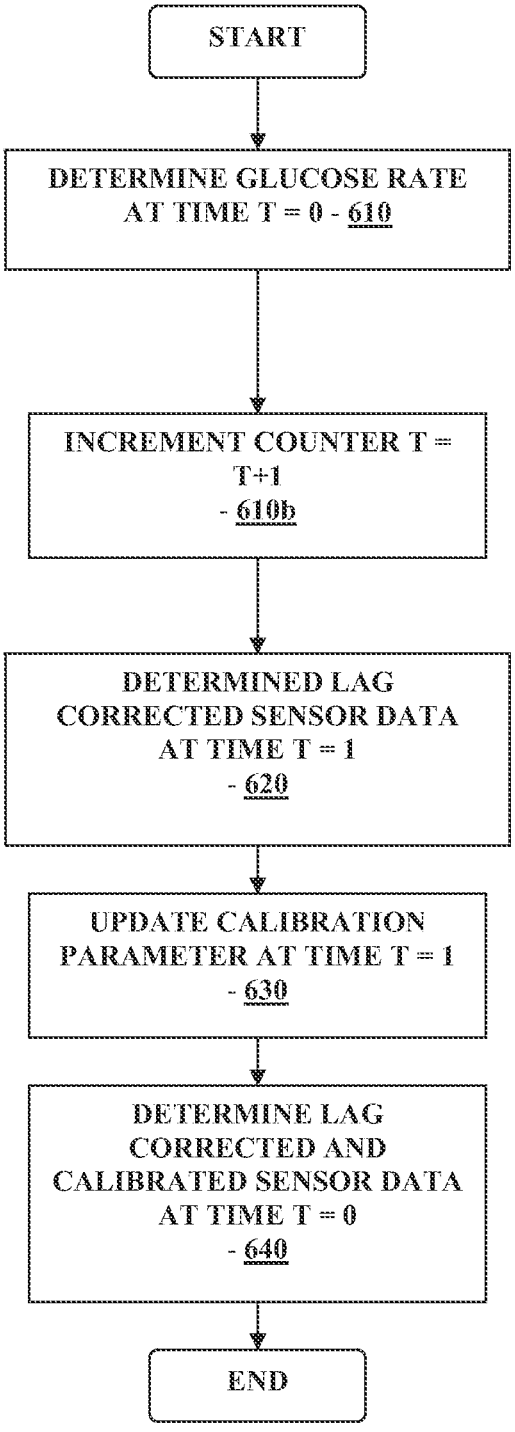
START
DETERMINE GLUCOSE RATE AT TIME T = 0 - 610
INCREMENT COUNTER T = T+1 - 610b
DETERMINED LAG CORRECTED SENSOR DATA AT TIME T = 1 - 620
UPDATE CALIBRATION PARAMETER AT TIME T = 1 - 630
DETERMINE LAG CORRECTED AND CALIBRATED SENSOR DATA AT TIME T = 0 - 640
END

FIGURE 6

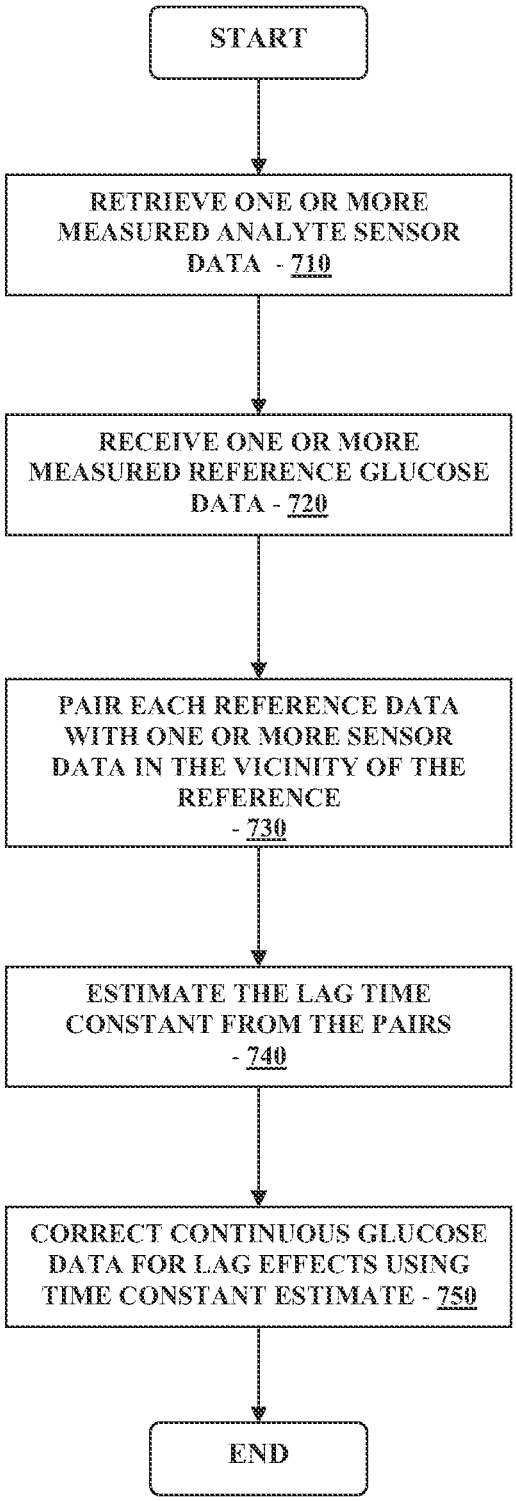
START
RETRIEVE ONE OR MORE MEASURED ANALYTE SENSOR DATA - 710
RECEIVE ONE OR MORE MEASURED REFERENCE GLUCOSE DATA - 720
PAIR EACH REFERENCE DATA WITH ONE OR MORE SENSOR DATA IN THE VICINITY OF THE REFERENCE - 730
ESTIMATE THE LAG TIME CONSTANT FROM THE PAIRS - 740
CORRECT CONTINUOUS GLUCOSE DATA FOR LAG EFFECTS USING TIME CONSTANT ESTIMATE - 750
END

FIGURE 7

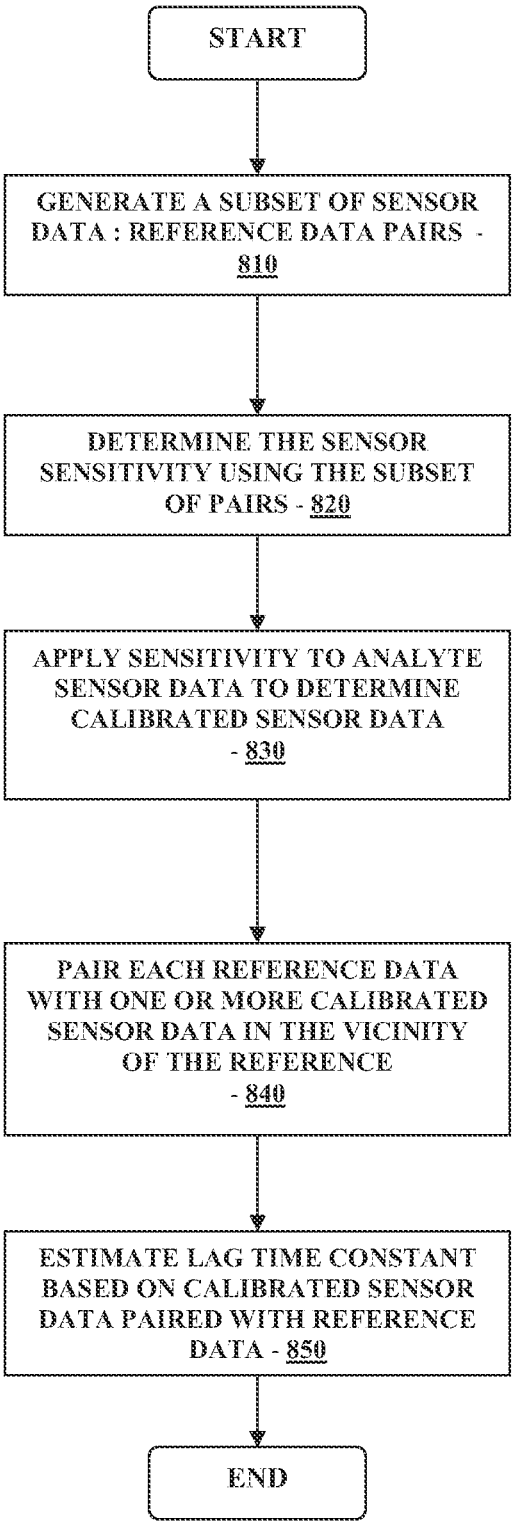
START
GENERATE A SUBSET OF SENSOR DATA : REFERENCE DATA PAIRS - 810
DETERMINE THE SENSOR SENSITIVITY USING THE SUBSET OF PAIRS - 820
APPLY SENSITIVITY TO ANALYTE SENSOR DATA TO DETERMINE CALIBRATED SENSOR DATA - 830
PAIR EACH REFERENCE DATA WITH ONE OR MORE CALIBRATED SENSOR DATA IN THE VICINITY OF THE REFERENCE - 840
ESTIMATE LAG TIME CONSTANT BASED ON CALIBRATED SENSOR DATA PAIRED WITH REFERENCE DATA - 850
END

FIGURE 8

ANALYTE SENSOR WITH TIME LAG COMPENSATION

RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 12/363,706 filed Jan. 30, 2009, now U.S. Pat. No. 8,473,022, which claims priority under §35 U.S.C. 119(e) to U.S. Provisional Application No. 61/025,290 filed Jan. 31, 2008, and is related to U.S. patent application Ser. No. 11/537,991 filed on Oct. 2, 2006, now U.S. Pat. No. 7,618,369, each assigned to the Assignee of the present application Abbott Diabetes Care Inc., of Alameda, Calif., the disclosures of each of which are incorporated herein by reference for all purposes.

BACKGROUND

Analyte, e.g., glucose monitoring systems including continuous and discrete monitoring systems generally include a small, lightweight battery powered and microprocessor controlled system which is configured to detect signals proportional to the corresponding measured glucose levels using an electrometer, and RF signals to transmit the collected data. One aspect of certain analyte monitoring systems include a transcutaneous or subcutaneous analyte sensor configuration which is, for example, partially mounted on the skin of a subject whose analyte level is to be monitored. The sensor cell may use a two or three-electrode (work, reference and counter electrodes) configuration driven by a controlled potential (potentiostat) analog circuit connected through a contact system.

The analyte sensor may be configured so that at least a portion thereof is placed under the skin of the patient so as to detect the analyte levels of the patient. In embodiments in which a portion is below the skin and a portion is above, the portion above the skin may be directly or indirectly connected with the transmitter unit. The transmitter unit is configured to transmit the analyte levels, e.g., in the form of current, detected by the sensor over a wireless (or wired) communication link such as an RF (radio frequency) communication link to a receiver/monitor unit. The receiver/monitor unit performs data analysis, among others on the received analyte levels to generate information pertaining to the monitored analyte levels.

To obtain accurate data from the analyte sensor, calibration may be necessary. In certain instances, blood glucose measurements are periodically obtained using, for example, a conventional analyte test strip and blood glucose meter, and the measured blood glucose values are used to calibrate the sensors. Indeed, the patient may calibrate each new analyte sensor using for example, capillary blood glucose measurements. Due to a lag factor between the monitored data and the measured blood glucose values, an error may be introduced in the monitored data.

In view of the foregoing, it would be desirable to have a method and system for calibrating analyte sensors of an analyte monitoring system to account for such lag errors in analyte monitoring systems.

SUMMARY

In one embodiment, methods including determining a calibration parameter associated with a detected analyte value, calibrating the analyte value based on the calibration parameter, and dynamically updating the calibration parameter is disclosed. Devices, systems and algorithms (e.g., embodied on computer readable medium) for performing such methods are also provided.

These and other objects, features and advantages of the present disclosure will become more fully apparent from the following detailed description of the embodiments, the appended claims and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a block diagram of a data monitoring and management system for practicing one or more embodiments of the present disclosure;

FIG. **2** is a block diagram of the transmitter unit of the data monitoring and management system shown in FIG. **1** in accordance with one embodiment of the present disclosure;

FIG. **3** is a block diagram of the receiver/monitor unit of the data monitoring and management system shown in FIG. **1** in accordance with one embodiment of the present disclosure;

FIG. **4** is a flowchart illustrating an overall dynamically updating calibration in accordance with one embodiment of the present disclosure;

FIG. **5** is a flowchart illustrating the lag correction and calibration routine of the overall dynamically updating calibration shown in FIG. **4** in accordance with one embodiment of the present disclosure;

FIG. **6** is a flowchart illustrating the lag correction and dynamically updating calibration routine of the overall dynamically updating calibration shown in FIG. **4** in accordance with one embodiment of the present disclosure;

FIG. **7** is a flowchart illustrating a method for estimating the lag time constant from sensor analyte data and reference measurements in accordance with one embodiment of the present disclosure; and

FIG. **8** is a flowchart illustrating lag time constant compensated analyte sensor data in accordance with one embodiment of the present disclosure.

DETAILED DESCRIPTION

As described in further detail below, in accordance with the various embodiments of the present disclosure, there is provided a method and system for calibration of analyte sensors to reduce errors in the sensor measurements. In particular, within the scope of the present disclosure, there are provided method and system for calibrating subcutaneous or transcutaneously positioned analyte sensors to compensate for time lag errors associated with an analyte sensor.

FIG. **1** illustrates a data monitoring and management system such as, for example, analyte (e.g., glucose) monitoring system **100** in accordance with one embodiment of the present disclosure. The subject invention is further described primarily with respect to a glucose monitoring system for convenience and such description is in no way intended to limit the scope of the invention. It is to be understood that the analyte monitoring system may be configured to monitor a variety of analytes, e.g., lactate, and the like. For example, analytes that may be monitored include but are not limited to, for example, acetyl choline, amylase, bilirubin, cholesterol, chorionic gonadotropin, creatine kinase (e.g., CK-MB), creatine, DNA, fructosamine, glucose, glutamine, growth hormones, hormones, ketones, lactate, peroxide, prostate-specific antigen, prothrombin, RNA, thyroid stimulating hormone, and troponin. The concentration of drugs, such as, for example, antibiotics (e.g., gentamicin, vancomycin, and the like), digitoxin, digoxin, drugs of abuse, theophylline, and warfarin, may also be monitored.

The analyte monitoring system **100** includes a sensor **101**, a transmitter unit **102** directly or indirectly coupled to the sensor **101**, and a primary receiver unit **104** which is configured to communicate with the transmitter unit **102** via a communication link **103**. The primary receiver unit **104** may be further configured to transmit data to a data processing terminal **105** for evaluating the data received by the primary receiver unit **104**. Moreover, the data processing terminal in one embodiment may be configured to receive data directly from the transmitter unit **102** via a communication link which may optionally be configured for bi-directional communication.

Also shown in FIG. **1** is an optional secondary receiver unit **106** which is operatively coupled to the communication link and configured to receive data transmitted from the transmitter unit **102**. Moreover, as shown in the Figure, the secondary receiver unit **106** is configured to communicate with the primary receiver unit **104** as well as the data processing terminal **105**. Indeed, the secondary receiver unit **106** may be configured for bi-directional wireless communication with each of the primary receiver unit **104** and the data processing terminal **105**. As discussed in further detail below, in one embodiment of the present disclosure, the secondary receiver unit **106** may be configured to include a limited number of functions and features as compared with the primary receiver unit **104**. As such, the secondary receiver unit **106** may be configured substantially in a smaller compact housing or embodied in a device such as a wrist watch, for example. Alternatively, the secondary receiver unit **106** may be configured with the same or substantially similar functionality as the primary receiver unit **104**, and may be configured to be used in conjunction with a docking cradle unit for placement by bedside, for night time monitoring, and/or bi-directional communication device.

Only one sensor **101**, transmitter unit **102**, communication link **103**, and data processing terminal **105** are shown in the embodiment of the analyte monitoring system **100** illustrated in FIG. **1**. However, it will be appreciated by one of ordinary skill in the art that the analyte monitoring system **100** may include one or more sensor **101**, transmitter unit **102**, communication link **103**, and data processing terminal **105**. Moreover, within the scope of the present disclosure, the analyte monitoring system **100** may be a continuous monitoring system, or semi-continuous, or a discrete monitoring system. In a multi-component environment, each device is configured to be uniquely identified by each of the other devices in the system so that communication conflict is readily resolved between the various components within the analyte monitoring system **100**.

In one embodiment of the present disclosure, the sensor **101** is physically positioned in or on the body of a user whose analyte level is being monitored. In one aspect, the sensor **101** may be configured to use one or more of coulometric, amperometric, potentiometric or conductimetric approaches to measure the analyte level being monitored. The sensor **101** may be configured to continuously sample the analyte of the user and the sampled analyte may be converted into a corresponding data signal for transmission by the transmitter unit **102**. In one embodiment, the transmitter unit **102** is mounted on the sensor **101** so that both devices are positioned on the user's body. The transmitter unit **102** performs data processing such as filtering and encoding on data signals, each of which corresponds to a sampled analyte level of the user, for transmission to the primary receiver unit **104** via the communication link **103**.

In one embodiment, the analyte monitoring system **100** is configured as a one-way RF communication path from the transmitter unit **102** to the primary receiver unit **104**. In such embodiment, the transmitter unit **102** may transmit the sampled data signals received from the sensor **101** without acknowledgement from the primary receiver unit **104** that the transmitted sampled data signals have been received (in other embodiments there may be acknowledgement). For example, the transmitter unit **102** may be configured to transmit the encoded sampled data signals at a fixed rate (e.g., at one minute intervals or other interval) after the completion of the initial power on procedure. Likewise, the primary receiver unit **104** may be configured to detect such transmitted encoded sampled data signals at predetermined time intervals. Alternatively, the analyte monitoring system **100** may be configured with a bi-directional RF (or otherwise) communication between the transmitter unit **102** and the primary receiver unit **104**.

Additionally, in one aspect, the primary receiver unit **104** may include two sections. The first section is an analog interface section that is configured to communicate with the transmitter unit **102** via the communication link **103**. In one embodiment, the analog interface section may include an RF receiver and an antenna for receiving and amplifying the data signals from the transmitter unit **102**, which are thereafter, demodulated with a local oscillator and filtered through a band-pass filter. The second section of the primary receiver unit **104** is a data processing section which is configured to process the data signals received from the transmitter unit **102** such as by performing data decoding, error detection and correction, data clock generation, and data bit recovery.

In operation in certain embodiments, upon completing a power-on procedure if required, the primary receiver unit **104** is configured to detect the presence of the transmitter unit **102** within its range based on, for example, the strength of the detected data signals received from the transmitter unit **102** or a predetermined transmitter identification information. Upon successful synchronization with the corresponding transmitter unit **102**, the primary receiver unit **104** is configured to begin receiving from the transmitter unit **102** data signals corresponding to the user's detected analyte level. More specifically, the primary receiver unit **104** in one embodiment is configured to perform synchronized time hopping with the corresponding synchronized transmitter unit **102** via the communication link **103** to obtain the user's detected analyte level.

Referring again to FIG. **1**, the data processing terminal **105** may include a personal computer, a portable computer such as a laptop or a handheld device (e.g., personal digital assistants (PDAs), telephone such as a cellular telephone), and the like, each of which may be configured for data communication with the receiver via a wired or a wireless connection. Additionally, the data processing terminal **105** may further be connected to a data network (not shown) for storing, retrieving and updating data corresponding to the detected analyte level of the user.

Within the scope of the present disclosure, the data processing terminal **105** may include an infusion device such as an insulin infusion pump or the like, which may be configured to administer a drug such as, for example insulin, to users, and which may be configured to communicate with the receiver unit **104** for receiving, among others, the measured analyte level. Alternatively, the receiver unit **104** may be configured to integrate an infusion device therein so that the receiver unit **104** is configured to administer insulin therapy to patients, for example, for administering and modifying basal profiles, as well as for determining appropriate boluses for administration based on, among others, the detected analyte levels received from the transmitter unit **102**.

Additionally, the transmitter unit **102**, the primary receiver unit **104** and the data processing terminal **105** may each be configured for bi-directional wireless communication such that each of the transmitter unit **102**, the primary receiver unit **104** and the data processing terminal **105** may be configured to communicate (that is, transmit data to and receive data from) with each other via the wireless communication link **103**. More specifically, the data processing terminal **105** may in one embodiment be configured to receive data directly from the transmitter unit **102** via a communication link, where the communication link, as described above, may be configured for bi-directional communication.

In this embodiment, the data processing terminal **105** which may include an insulin pump, may be configured to receive the analyte signals from the transmitter unit **102**, and thus, incorporate the functions of the receiver unit **104** including data processing for managing the patient's insulin therapy and analyte monitoring. In one embodiment, the communication link **103** may include one or more of an RF communication protocol, an infrared communication protocol, a Bluetooth® enabled communication protocol, an 802.11x wireless communication protocol, or an equivalent wireless communication protocol which would allow secure, wireless communication of several units (for example, per HIPAA requirements) while avoiding potential data collision and interference.

FIG. **2** is a block diagram of the transmitter of the data monitoring and detection system shown in FIG. **1** in accordance with one embodiment of the present disclosure. Referring to the Figure, the transmitter unit **102** in one embodiment includes an analog interface **201** configured to communicate with the sensor **101** (FIG. **1**), a user input **202**, and a temperature detection section **203**, each of which is operatively coupled to a transmitter processor **204** such as a central processing unit (CPU). As can be seen from FIG. **2**, there are provided four contacts, three of which are electrodes—work electrode (W) **210**, guard contact (G) **211**, reference electrode (R) **212**, and counter electrode (C) **213**, each operatively coupled to the analog interface **201** of the transmitter unit **102** for connection to the sensor **101** (FIG. **1**). In one embodiment, each of the work electrode (W) **210**, guard contact (G) **211**, reference electrode (R) **212**, and counter electrode (C) **213** may be made using a conductive material that may be applied in any suitable manner, e.g., printed or etched, for example, such as carbon, gold, and the like, which may be printed, or metal foil (e.g., gold) which may be etched.

Further shown in FIG. **2** are a transmitter serial communication section **205** and an RF transmitter **206**, each of which is also operatively coupled to the transmitter processor **204**. Moreover, a power supply **207** such as a battery is also provided in the transmitter unit **102** to provide the necessary power for the transmitter unit **102**. Additionally, as can be seen from the Figure, clock **208** is provided to, among others, supply real time information to the transmitter processor **204**.

In one embodiment, a unidirectional input path is established from the sensor **101** (FIG. **1**) and/or manufacturing and testing equipment to the analog interface **201** of the transmitter unit **102**, while a unidirectional output is established from the output of the RF transmitter **206** of the transmitter unit **102** for transmission to the primary receiver unit **104**. In this manner, a data path is shown in FIG. **2** between the aforementioned unidirectional input and output via a dedicated link **209** from the analog interface **201** to serial communication section **205**, thereafter to the processor **204**, and then to the RF transmitter **206**. As such, in one embodiment, via the data path described above, the transmitter unit **102** is configured to transmit to the primary receiver unit **104** (FIG. **1**), via the communication link **103** (FIG. **1**), processed and encoded data signals received from the sensor **101** (FIG. **1**). Additionally, the unidirectional communication data path between the analog interface **201** and the RF transmitter **206** discussed above allows for the configuration of the transmitter unit **102** for operation upon completion of the manufacturing process as well as for direct communication for diagnostic and testing purposes.

As discussed above, the transmitter processor **204** is configured to transmit control signals to the various sections of the transmitter unit **102** during the operation of the transmitter unit **102**. In one embodiment, the transmitter processor **204** also includes a memory (not shown) for storing data such as the identification information for the transmitter unit **102**, as well as the data signals received from the sensor **101**. The stored information may be retrieved and processed for transmission to the primary receiver unit **104** under the control of the transmitter processor **204**. Furthermore, the power supply **207** may include a commercially available battery.

The transmitter unit **102** is also configured such that the power supply section **207** is capable of providing power to the transmitter for a predetermined minimum continuous operation time period and also with a predetermined minimum shelf life time period such as, for example, a minimum of about three months of continuous operation after having been stored for about eighteen months in a low-power (non-operating) mode. In one embodiment, this may be achieved by the transmitter processor **204** operating in low power modes in the non-operating state, for example, drawing no more than approximately 1 μA of current. Indeed, in one embodiment, the final step during the manufacturing process of the transmitter unit **102** may place the transmitter unit **102** in the lower power, non-operating state (i.e., post-manufacture sleep mode). In this manner, the shelf life of the transmitter unit **102** may be significantly improved. Moreover, as shown in FIG. **2**, while the power supply unit **207** is shown as coupled to the processor **204**, and as such, the processor **204** is configured to provide control of the power supply unit **207**, it should be noted that within the scope of the present disclosure, the power supply unit **207** is configured to provide the necessary power to each of the components of the transmitter unit **102** shown in FIG. **2**.

Referring back to FIG. **2**, the power supply section **207** of the transmitter unit **102** in one embodiment may include a rechargeable battery unit that may be recharged by a separate power supply recharging unit (for example, provided in the receiver unit **104**) so that the transmitter unit **102** may be powered for a longer period of usage time. Moreover, in one embodiment, the transmitter unit **102** may be configured without a battery in the power supply section **207**, in which case the transmitter unit **102** may be configured to receive power from an external power supply source (for example, a battery) as discussed in further detail below.

Referring yet again to FIG. **2**, the optional temperature detection section **203** of the transmitter unit **102** is configured to monitor the temperature of the skin near the sensor insertion site. The temperature reading may be used to adjust the analyte readings obtained from the analog interface **201**. The RF transmitter **206** of the transmitter unit **102** may be configured for operation in the frequency band of 315 MHz to 322 MHz, for example, in the United States. Further, in one embodiment, the RF transmitter **206** is configured to modulate the carrier frequency by performing Frequency Shift Keying and Manchester encoding. In one embodiment, the data transmission rate is 19,200 symbols per second, with a minimum transmission range for communication with the primary receiver unit **104**.

Referring yet again to FIG. **2**, also shown is a leak detection circuit **214** coupled to the guard contact (G) **211** and the processor **204** in the transmitter unit **102** of the data monitoring and management system **100**. The leak detection circuit **214** in accordance with one embodiment of the present disclosure may be configured to detect leakage current in the sensor **101** to determine whether the measured sensor data is corrupt or whether the measured data from the sensor **101** is accurate.

Additional detailed description of the continuous analyte monitoring system, its various components including the functional descriptions of the transmitter are provided in U.S. Pat. No. 6,175,752 issued Jan. 16, 2001 entitled "Analyte Monitoring Device and Methods of Use", and in U.S. application Ser. No. 10/745,878 filed Dec. 26, 2003, now U.S. Pat. No. 7,811,231, entitled "Continuous Glucose Monitoring System and Methods of Use", each assigned to the Assignee of the present application.

FIG. **3** is a block diagram of the receiver/monitor unit of the data monitoring and management system shown in FIG. **1** in accordance with one embodiment of the present disclosure. Referring to FIG. **3**, the primary receiver unit **104** includes a blood glucose test strip interface **301**, an RF receiver **302**, an input **303**, a temperature detection section **304**, and a clock **305**, each of which is operatively coupled to a receiver processor **307**. As can be further seen from the Figure, the primary receiver unit **104** also includes a power supply **306** operatively coupled to a power conversion and monitoring section **308**. Further, the power conversion and monitoring section **308** is also coupled to the receiver processor **307**. Moreover, also shown are a receiver serial communication section **309**, and an output **310**, each operatively coupled to the receiver processor **307**.

In one embodiment, the test strip interface **301** includes a glucose level testing portion to receive a manual insertion of a glucose test strip, and thereby determine and display the glucose level of the test strip on the output **310** of the primary receiver unit **104**. This manual testing of glucose can be used to calibrate sensor **101**. The RF receiver **302** is configured to communicate, via the communication link **103** (FIG. **1**) with the RF transmitter **206** of the transmitter unit **102**, to receive encoded data signals from the transmitter unit **102** for, among others, signal mixing, demodulation, and other data processing. The input **303** of the primary receiver unit **104** is configured to allow the user to enter information into the primary receiver unit **104** as needed. In one aspect, the input **303** may include one or more keys of a keypad, a touch-sensitive screen, or a voice-activated input command unit. The temperature detection section **304** is configured to provide temperature information of the primary receiver unit **104** to the receiver processor **307**, while the clock **305** provides, among others, real time information to the receiver processor **307**.

Each of the various components of the primary receiver unit **104** shown in FIG. **3** is powered by the power supply **306** which, in one embodiment, includes a battery. Furthermore, the power conversion and monitoring section **308** is configured to monitor the power usage by the various components in the primary receiver unit **104** for effective power management and to alert the user, for example, in the event of power usage which renders the primary receiver unit **104** in sub-optimal operating conditions. An example of such sub-optimal operating condition may include, for example, operating the vibration output mode (as discussed below) for a period of time thus substantially draining the power supply **306** while the processor **307** (thus, the primary receiver unit **104**) is turned on. Moreover, the power conversion and monitoring section **308** may additionally be configured to include a reverse polarity protection circuit such as a field effect transistor (FET) configured as a battery activated switch.

The serial communication section **309** in the primary receiver unit **104** is configured to provide a bi-directional communication path from the testing and/or manufacturing equipment for, among others, initialization, testing, and configuration of the primary receiver unit **104**. Serial communication section **309** can also be used to upload data to a computer, such as time-stamped blood glucose data. The communication link with an external device (not shown) can be made, for example, by cable, infrared (IR) or RF link. The output **310** of the primary receiver unit **104** is configured to provide, among others, a graphical user interface (GUI) such as a liquid crystal display (LCD) for displaying information. Additionally, the output **310** may also include an integrated speaker for outputting audible signals as well as to provide vibration output as commonly found in handheld electronic devices, such as mobile telephones presently available. In a further embodiment, the primary receiver unit **104** also includes an electro-luminescent lamp configured to provide backlighting to the output **310** for output visual display in dark ambient surroundings.

Referring back to FIG. **3**, the primary receiver unit **104** in one embodiment may also include a storage section such as a programmable, non-volatile memory device as part of the processor **307**, or provided separately in the primary receiver unit **104**, operatively coupled to the processor **307**. The processor **307** may be configured to perform Manchester decoding as well as error detection and correction upon the encoded data signals received from the transmitter unit **102** via the communication link **103**.

FIG. **4** is a flowchart illustrating an overall dynamically updating calibration in accordance with various embodiments of the present disclosure. Referring to FIG. **4**, a counter such as a calibration counter is triggered to perform calibration of the monitored data such as the analyte data received from the transmitter unit **102** (FIG. **1**). In one aspect, the calibration may be performed on calibrated data, or on the uncalibrated data, for example, on the analyte data received prior to the initial calibration performed. In one embodiment, the calibration counter may include a timer or a clock which may be configured to prompt the user or the patient to initiate the acquisition of reference data (e.g., blood glucose reference data, e.g., obtained using a test strip/meter system) at predetermined time intervals. When the calibration counter is initially triggered, the time counter T is initialized to zero (0). Thereafter, a calibration parameter is determined based on, for example, the acquired reference data and the monitored sensor data at time T=0. Moreover, in one embodiment, the monitored sensor data may be updated based on the calibration parameter. In one embodiment, the calibration parameter may include a sensor sensitivity value associated with the analyte sensor **101** (FIG. **1**) configured to monitor the analyte levels of the patient.

As described in further detail below, for example, in conjunction with FIG. **5**, in particular embodiments, during the initial calibration stage at T=0, a reference glucose value is determined, for example, such as a capillary blood glucose value using a blood glucose determination system such as Freestyle® blood glucose monitoring system or Precision® blood glucose monitoring system available from Abbott Diabetes Care Inc., Alameda, Calif. In certain embodiments, an analyte meter may be integrated into the receiver unit. In addition, the monitored sensor data at or near the calibration time (T=0) is retrieved which may include the monitored sensor data at time T=T−1, at time T=T+1, or any other

suitable time period (for example, from the processing and storage unit **307** (FIG. **3**) of the receiver unit **104** (FIG. **1**)).

More specifically, in one embodiment, the monitored sensor data at the calibration time (T=0) may include one or more monitored sensor data in addition to the monitored sensor data point at the calibration time (T=0). That is, in one embodiment, the monitored sensor data at the calibration time (T=0) may include all monitored sensor data available for retrieval from the receiver unit **104** (FIG. **1**) at the calibration time (T=0). For example, to reduce the contribution of noise in the measured sensor data, an average of the two most recent sensor data may be associated with the monitored sensor data at the calibration time (T=0).

The monitored sensor data at a predetermined time may include, in particular embodiments, an estimate of the sensor data at the predetermined time as determined by the one or more filters which may be configured to use the monitored sensor data up to and including the data point at the predetermined time (for example, up to the data point at calibration time (T=0)). In one embodiment, one or more filters such as a finite impulse response (FIR) filter may be used to determine the best estimate at a predetermined time using a finite window of monitored sensor data up to the current or most recent monitored sensor data point.

Referring back to FIG. **4**, after determining the calibration parameter and updating the monitored data at the calibration time (T=0), the counter is incremented by one (1), and dynamic, real-time update of the calibration parameter is performed. In one embodiment, the counter may be configured to increment by one with each reception of sensor data from the transmitter unit **102** (FIG. **1**). After dynamically updating the calibration parameter at the subsequent incremented time (T=1), it is determined whether the counter has reached a predetermined count (for example, set at seven (7)). If it is determined that the counter has not reached the predetermined count, then the routine in one embodiment returns to step **430** where the counter is incremented by one (1) and the dynamically updating calibration parameter and monitored sensor data is performed for monitored data at the second subsequent incremented time (T=2).

On the other hand, if it is determined that the counter has reached the predetermined count, then in one embodiment, subsequent monitored sensor data may be updated based on the dynamically updated calibration parameter and/or updated monitored sensor data. Thereafter, in particular embodiments, it is determined whether further or subsequent lag correction will likely not yield more accurate monitored data values (or with less errors). Therefore, in one embodiment, the routine terminates and awaits for the subsequent calibration time, for example, to repeat the processes described above in conjunction with FIG. **4**. When a procedure such as described in FIG. **4** has been successfully completed, routines such as determining lag time constant based on calibrated sensor data **740** (FIG. **7**) may be updated in order to obtain a better estimate.

In this manner, there are provided methods and system for dynamically, and in particular embodiments, in real-time, obtaining reference data at a first predetermined time, receiving measured data prior to and including (or near) the first predetermined time, calculating a first calibration parameter (or parameters) using the data, calibrating the measured data based on the calibration parameter, receiving measured data at a second predetermined time, updating the calibration parameter based on all of the previous data and the newly received measured data, calibrating the newly received measured data based on the updated calibration parameter, and repeating a number of times the process of receiving new measurement data, updating the calibration parameter, calibrating the newly received measurement data, and calibrating any newly received measurement data with the fully updated calibration parameter.

A method in a further embodiment may include performing lag compensation on the measured data that is used to update the calibration parameter. Lag compensation may optionally be performed on the measured data that is calibrated or on uncalibrated data. A method in a further embodiment includes filtering the measured data that is used to update the calibration parameter.

FIG. **5** is a flowchart illustrating the lag correction and calibration routine of the overall dynamically updating calibration shown in FIG. **4** in accordance with one embodiment of the present disclosure. Referring to FIG. **5**, the determination of calibration parameter and updating the monitored analyte level at the calibration time (T=0) is described in further detail. More specifically, in one embodiment, a capillary blood glucose value is determined at the calibration time (T=0), and the monitored analyte value at the calibration time is retrieved from the receiver unit **104** of the monitoring system **100** (FIG. **1**).

Thereafter, a rate of change of the monitored data at the calibration time (T=0) is determined. In one embodiment, the rate of change of the monitored data at the calibration time (T=0) may be determined using one or more filters including, but not limited to infinite impulse response (IIR) filter, finite impulse response (FIR) filter, backward and/or forward smoothing techniques (e.g., Kalman filtering technique), or any other equivalent one or more causal filters that balance signal noise reduction with lag correction.

Upon determining the rate of change of the monitored data at the calibration time (T=0), the monitored data at the calibration time (T=0) is updated. In one embodiment, the updated monitored sensor data may include lag corrected monitored data at the calibration time (T=0). Optionally, the lag correction for the monitored data at the calibration time (T=0) may be skipped and not performed. In one embodiment, the lag corrected monitored data at the calibration time (T=0) may be determined by applying the determined rate of change of the monitored data at the calibration time (T=0) to a predetermined constant value. In one embodiment, the predetermined constant value may include, a predetermined time constant.

For example, in one embodiment, the predetermined time constant may include a fixed time constant in the range of approximately four to fifteen minutes, and which may be associated with the one or more of the patient physiological profile, one or more attributes associated with the monitoring system **100** (including, for example but not limited to, the characteristics of the analyte sensor **101**). In a further aspect, the predetermined time constant may vary based on one or more factors including, for example, but not limited to the timing and amount of food intake by the patient, exogenous insulin intake, physical activities by the patient such as exercise, or any other factors that may affect the time constant, and which may be empirically determined.

Referring again to FIG. **5**, the calibration parameter (for example, the sensitivity of the analyte sensor **101** FIG. **1**), may be determined for example, in one embodiment, by determining the ratio of the monitored data (optionally lag corrected) at the calibration time (T=0) and the reference data obtained using, for example, the blood glucose meter as described above. In one embodiment, the calibration parameter may be determined by dividing the monitored data at the calibration time (T=0) by the reference data such as the capillary blood glucose value at the calibration time (T=0).

Thereafter, in one embodiment, the calibrated and updated monitored sensor data at the calibration time (T=0) is determined based upon the monitored data (optionally lag corrected) and the calibration parameter as determined above. For example, in one embodiment, the calibrated and updated monitored sensor data at the calibration time (T=0) may be determined by dividing the lag corrected monitored data at calibration time (T=0) by the determined calibration parameter.

FIG. **6** is a flowchart illustrating the lag correction and dynamically updating calibration routine of the overall dynamically updating calibration shown in FIG. **4** in accordance with one embodiment of the present disclosure. Referring to FIGS. **4** and **6**, with the counter incremented by one (see step **430** of FIG. **4** and step **610***b* of FIG. **6**), the analyte value at the subsequent incremented time (T=1) is retrieved from, for example, the processing and storage unit **307** (FIG. **3**) of the receiver unit **104**. In particular, in one embodiment, the rate of change of the monitored data at the calibration time (T=0) is updated based on the monitored data value at the subsequent incremented time (T=1). In other words, the process starts with the determination of glucose rate of change at calibration time (T=0) **610** in FIG. **6**. At the next time increment, this value is revised using the monitored data values at calibration time (T=0) and prior data and at the subsequent incremented time (T=1) (see **620** and **630** of FIG. **6**), the rate of change of the monitored data at the calibration time (T=0) may be estimated with an improved accuracy at T=1 (see **640** of FIG. **6**). Again, in one embodiment, the rate of change may be determined based on one or more of, but not limited to, infinite impulse response (IIR) filter, finite impulse response (FIR) filter, backward and/or forward smoothing techniques (e.g., Kalman filtering technique), or any other equivalent filtering or smoothing techniques.

With the updated rate of change at the calibration time (T=0) determined, monitored data (optionally lag corrected) at calibration time (T=0) is updated. That is, in one embodiment, the lag corrected sensor data at the calibration time (T=0) is updated based on the prior lag corrected and calibrated data at calibration time (T=0), and in conjunction with the predetermined constant (for example, the predetermined time constant discussed above), and the updated rate of change of the monitored data at the calibration time (T=0). For example, in one embodiment, the lag corrected monitored data at the calibration time (T=0) is updated or determined by taking the sum of the lag corrected and calibration sensor value at calibration time (T=0) as determined above, with the updated rate of change of monitored data at calibration time (T=0) multiplied by the predetermined constant. In other words, in one embodiment, the updated rate of change of the monitored data at calibration time (T=0) may be multiplied by the predetermined constant, and thereafter, the resulting value is added to the lag corrected and calibrated monitored data at the calibration time (T=0) previously determined (see for example, step **420**).

Referring again to FIG. **6**, after determining the updated lag corrected monitored data at calibration time (T=0) based on monitored data at the subsequent incremented time (T=1) as described above, in one embodiment, the calibration parameter (for example, the sensitivity of the sensor **101** (FIG. **1**)) is updated based on the updated lag corrected monitored data at calibration time (T=0) described above. In particular, in one embodiment, the calibration parameter may be updated by determining the ratio of the updated lag corrected monitored data at calibration time (T=0) and the reference value (for example, the capillary blood glucose value) determined at calibration time (T=0).

After updating the calibration parameter as described above, in one embodiment, the lag corrected and calibrated monitored data at the subsequent incremented time (T=1) is determined based on the updated calibration parameter value. For example, in one embodiment, the monitored sensor data at the subsequent incremented time (T=1) in one embodiment may be divided by the updated sensitivity to determine the dynamically lag corrected and calibrated monitored sensor data at the subsequent incremented time (T=1).

In another embodiment, the dynamically lag corrected and calibrated monitored sensor data at the subsequent incremented time (T=1) may be determined based on the updated calibration parameter and the dynamically lag corrected monitored sensor data at the subsequent incremented time (T=1). In this case, the dynamically updated sensor data at the subsequent incremented time (T=1) in one embodiment may be determined by calculating the rate of change of the monitored data at the subsequent incremented time (T=1) using similar filtering techniques as described above, and applying the predetermined constant (for example, the predetermined time constant discussed above), the result of which is then added to the detected or monitored data at the subsequent incremented time (T=1). In other words, in one embodiment, the calculated rate of change of the monitored data at the subsequent incremented time (T=1) is multiplied by the predetermined time constant, and the resulting value is added to the monitored data value at the subsequent incremented time (T=1). This sum in one embodiment represents the dynamically updated monitored sensor data at the subsequent incremented time (T=1).

In this manner, in one embodiment, lag correction of analyte sensor data may be pseudo-retrospectively (or substantially in real time) updated using the monitored analyte data stream substantially continuously detected by the sensor **101** (FIG. **1**) with the dynamic updating of the calibration parameter. Thus, in one aspect, lag error or error due to lag compensation may be overcome by, for example, updating the sensor sensitivity retrospectively with each value of the detected or monitored analyte levels. Accordingly, in one embodiment, calibration inaccuracies due to change (for example, rapid acceleration) of analyte levels after performing discrete calibration may be mitigated by updating the calibration routine taking into consideration the near immediate post calibration analyte sensor data to obtain a more reliable and accurate value associated with the rate of change of the monitored analyte levels. In one embodiment, the overall system accuracy of the monitored and detected analyte values may be improved.

FIG. **7** is a flowchart illustrating a method for estimating the lag time constant from sensor analyte data and reference measurements in accordance with one embodiment of the present disclosure. This method can be employed in real-time or offline, or components of the method may be one or the other. Referring to FIG. **7**, measured analyte sensor data for example, from a transcutaneously positioned analyte sensor may be obtained and/or retrieved from a memory or storage device operatively coupled to the analyte sensor (**710**). Thereafter, a reference glucose data measurement is performed and received, for example, from a blood glucose meter (**720**). Each of the reference glucose data is paired with one or more measured analyte sensor data in the same time vicinity as the reference data (**730**). That is, the pairing may be to select a single analyte sensor data closest in time to the time of the reference data. Alternatively, the pairing could be a number of analyte sensor data occurring before and after the reference data. Alternatively, the pairing could be between a value that is the result of a calculation using a number of analyte sensor

data occurring before and after the reference data; the calculation could be an average or some other appropriate form of filtering.

Referring back to FIG. **7**, thereafter, these pairs are used to estimate the lag time constant (**740**). This estimate could be performed using standard system identification techniques. For instance, a 2 or more dimensional least squares technique could be used to estimate the time constant, along with the sensor sensitivity. The preferred embodiment for estimating the time constant separates the estimation of the sensitivity from the estimation of the lag time constant, and is illustrated in FIG. **8**, and described later.

Once the estimate of the lag time constant is determined, it may be used to correct the sensor data for lag effects (**750**). In one aspect, calibration for lag effects may be corrected. In another aspect, each calibrated sensor data may be corrected for lag effects as described below.

Given a calibrated sensor providing a continuous stream of interstitial glucose G_i, lag correction routine used to improve calibration may also be used to provide a blood glucose estimate G_b. For example, consider a simple continuous time domain model of blood glucose-to-interstitial glucose dynamics:

$$\tau\dot{G}_i(t)=-G_i(t)+G_b(t)$$

where τ is the time constant, and $\dot{G}_i$ is the rate of change of glucose level G_i. Given that glucose G_i is available or determined by another module made possible by the latest calibration procedure, the rate of change of the glucose level $\dot{G}_i$ may be determined in one or more retrospectively or in real-time. The time constant τ is available or computed by another module.

One real-time example to obtain a sampled data estimate of the rate of change $\dot{G}_i$ at any time n is to use the average first difference of the past N sampled G_i data:

$$\hat{\dot{G}}_i(n) \approx \frac{\sum_{n=1}^{N} G_i(n) - G_i(n-1)}{NT_s}$$

where T_s is the sample time or the time interval between the sampled values of $G_i(n)$. The notation $\hat{\dot{G}}_i$ signifies that it is an estimate for $\dot{G}_i$. Other approaches to compute $\dot{G}_i$ include any other Finite Impulse Response (FIR) filters, Infinite Impulse Response (IIR) filters, Wiener filter, and Kalman filter.

Given these available and/or computed values, blood glucose estimate G_b can be computed by rearranging the blood glucose-to-interstitial glucose model in the following manner:

$$\hat{G}_b(n)=G_i(n)+\tau\hat{\dot{G}}_i(n)$$

where n is any time instance. Note that for improved noise rejection, the first term on the right hand side, $G_i(n)$, may be replaced by a filtered version. The filter can take any eligible forms such as the FIR filter, IIR filter, Wiener filter, or the Kalman filter.

In one embodiment, steps **730** and **740** are performed as a batch process. For instance, the receiver unit **104**, may perform the routines described at steps **730** and **740** periodically or continuously, after each reference measurement, with a batch of data saved on the receiver unit **104**. After each batch process, the lag time constant may be updated and used for subsequent real-time lag correction processes. Another embodiment may include the batch process to be performed external to the receiver unit in a computer terminal, for example. After the time constant is estimated, it may be downloaded or transmitted to the receiver unit to be used in subsequent real time lag correction processes.

In a further aspect, the routine illustrated in FIG. **7** may be performed retrospectively, for example, using a computer or server terminal. This may be used in applications where lag correction operations may be performed retrospectively.

FIG. **8** illustrates estimation of the lag time constant from the pairs **740** of FIG. **7** in one embodiment. The generation of a subset of pairs (**810**) may include generating a subset from pairs associated with sensor data absolute rate of change that is below a predetermined threshold. An example of the predetermined threshold includes 0.1 mg/dL/minute. An alternative predetermined threshold may be 6% change in the glucose estimate per minute. That is, the lag effects may be minimized if the rate of change is relatively low, and the subsequent estimation of the sensitivity (**820**) may be minimally affected by lag. Additionally, the included pairs may form a cluster of data in time. Other criteria for creating a subset of pairs may include a) data from a single sensor, b) data from a single subject, c) data from groups of patients or users, d) data associated with any particular conditions, such as data where all glucose is above some value, e) data that meets certain data quality conditions.

In the case where the criteria for generating a subset of pairs includes determining the glucose rate of change is below a predetermined glucose rate of change threshold, then the measured sensor data may be converted to preliminary glucose estimates using a preliminary sensitivity. The preliminary sensitivity may be determined by a variety of ways, including: the use of a nominal sensitivity assigned at the factor for a particular lot of sensors, the use of the median of the sensitivities calculated for each pair, or another suitable means. In the case where the criteria includes a percentage of signal change, then the determination of the preliminary sensitivity is not needed.

The pair subset criterion in one aspect may include a condition that the data be from one sensor. In this embodiment, the sensitivity is estimated (**820**) for one sensor and the lag time constant is subsequently estimated (**830-850**). The receiver unit may subsequently use this time constant in real time to correct calibration and glucose calculations for lag effects. Further, this process may be repeated for multiple sensors, and the resulting multiple lag time constant estimates could be combined to create a single estimate used for lag correction. A simple combination calculation may include an average; other combination calculations, such as an FIR filter or a median or a time weighted average.

The pair subset criterion may alternatively include that the data must be from one patient, over multiple sensors. This subset may be further segregated by sensor when determining sensor sensitivity (**820**) and applying the determined sensitivity to the analyte sensor data (**830**).

Referring back to FIG. **8**, the sensitivity of a subset of pairs is determined (**820**). In one aspect, a ratio for each reference data and associated sensor data (or value representing a combination of sensor data) are determined, and the median from this set of ratios is determined.

The sensitivity estimated is applied to the analyte sensor data (**830**) to generate the calibrated sensor data. Specifically, each sensor data point is divided by the sensitivity ratio to convert the sensor data from its native measurement units into glucose units. If the pair subsets (**810**) include data from multiple sensors, then the sensitivity estimated for each sensor is applied to the sensor data associated with that sensor.

Referring still to FIG. **8**, the calibrated sensor data is paired with reference data (**840**). In a further aspect, another pair

subset may be created to only include pairs where the glucose absolute rate of change based on the sensor exceeded a predetermined threshold, for example 0.75 mg/dL. In this case, the pairs associated with low glucose rate of change may be minimally informative to the lag time constant estimation. This may not be necessary to produce a result, but may be useful to reduce the amount of computation needed if this is desirable.

In step **850**, the pairs of calibrated sensor data and reference data are used to estimate the lag time constant. One embodiment of the time constant calculation is to assume that the interstitial fluid glucose level is connected to the blood glucose level by a simple first order differential expression:

$$\tau \frac{dI_{NAV}}{dt} = -I_{NAV} + SG_{REF}.$$

Here, τ, is the time constant, I_{NAV} is the sensor data measurement, S is the ratio of sensor current to blood glucose concentration (sensitivity), and G_{REF} is a blood glucose reference measurement. This equation may be solved for τ if the values of the other quantities can be estimated. One approach for estimation of the sensor data measurement and its time rate of change may require filtering of the signal in order to reduce the effect of high frequency noise. In one aspect, the sensor data may be fit in a time interval around the reference point, G_{REF}, to a low order polynomial via the least squares algorithm. Another embodiment is to use a causal or non-causal low-pass filter.

If more than one reference point is available, then there will be multiple values of the time constant τ, and in which case, a least squares approach may be applied

Accordingly, the identification of the sensitivity parameter may be isolated from that of the lag parameter. Moreover, in one aspect, data exclusion may be in the routine illustrated in FIG. **8**. In one embodiment, a paired point exclusion may be added just after calibrated sensor data is paired with reference data, where the exclusion criteria may be a constraint appropriate for improving the estimate of lag. For instance, if the lag time constant at high glucose values is desirable to determine, then a step could be added to exclude pairs associated with a reference below a predetermined glucose threshold.

In this manner, the time lag constant determination associated with an analyte sensor for lag correction may be implemented in a real time monitoring system such as one aspect of the analyte monitoring system **100**, or alternatively, may be used as an analysis too, for example, by a patient, a physician or a health care provider to improve the treatment of the patient based on improved physiological data associated with the patient with minimal errors.

Indeed, in one aspect, lag compensation of analyte sensor measurements may be tuned or adjusted to the particular analyte sensor in use by the patient or the user, resulting in improved accuracy of the overall analyte monitoring system **100**.

It is to be noted that, each step or routine associated each of the flowcharts illustrating the various embodiments of the present disclosure as shown in FIG. **4-8** do not have to be performed in the order shown in the Figures, unless described otherwise, and within the scope of the present disclosure, one or more step or routine in one or more figures described above may be performed or executed in an order different from the order shown in the respective figures.

Referring to the Figures above, in particular embodiments, the lag correction and calibration and updating of monitored sensor data may be performed by one or more processing units of the one or more receiver unit (**104**, **106**) the transmitter unit **102** or the data processing terminal/infusion section **105**. In addition, the one or more of the transmitter unit **102**, the primary receiver unit **104**, secondary receiver unit **106**, or the data processing terminal/infusion section **105** may also incorporate a blood glucose meter functionality, such that, the housing of the respective one or more of the transmitter unit **102**, the primary receiver unit **104**, secondary receiver unit **106**, or the data processing terminal/infusion section **105** may include a test strip port configured to receive a blood sample for determining one or more blood glucose levels of the patient.

In a further embodiment, the one or more of the transmitter unit **102**, the primary receiver unit **104**, secondary receiver unit **106**, or the data processing terminal/infusion section **105** may be configured to receive the blood glucose value wirelessly over a communication link from, for example, a glucose meter. In still a further embodiment, the user or patient manipulating or using the analyte monitoring system **100** (FIG. **1**) may manually input the blood glucose value using, for example, a user interface (for example, a keyboard, keypad, and the like) incorporated in the one or more of the transmitter unit **102**, the primary receiver unit **104**, secondary receiver unit **106**, or the data processing terminal/infusion section **105**.

A computer implemented method in accordance with one embodiment includes determining a rate of change of an analyte level monitored by an analyte sensor below a predetermined threshold, calibrating analyte data associated with the monitored analyte level received from analyte sensor based on a reference measurement, determining a time lag constant associated with the calibrated analyte data, and performing lag correction of the calibrated analyte data based on the determined time lag constant.

The method may include outputting the lag corrected calibrated analyte data.

In one aspect, the reference measurement may include a blood glucose measurement.

The reference measurement may be obtained within a predetermined time period relative to the monitored analyte level, where the predetermined time period may be less than approximately 30 minutes or greater than approximately 30 minutes, or any other suitable time range.

In one aspect, calibrating the analyte data may include determining a sensitivity value associated with the analyte sensor, where the sensitivity value may include a ratio of the analyte data and the corresponding reference measurement.

The analyte level may include glucose level.

In a further aspect, determining the rate of change may include determining a rate of increase or a rate of decrease of the monitored analyte level for a predefined time period.

An apparatus in accordance with one embodiment may include one or more processing units, and a memory for storing instructions which, when executed by the one or more processors, causes the one or more processing units to determine a rate of change of an analyte level monitored by an analyte sensor below a predetermined threshold, calibrate analyte data associated with the monitored analyte level received from analyte sensor based on a reference measurement, determine a time lag constant associated with the calibrated analyte data, and perform lag correction of the calibrated analyte data based on the determined time lag constant.

The memory may be further configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to output the lag corrected calibrated analyte data.

In a further aspect, the apparatus may include a communication module operatively coupled to the one or more processing units, the communication module configured to receive the reference measurement within a predetermined time period relative to the monitored analyte level, where the predetermined time period may be less than approximately 30 minutes or greater than approximately 30 minutes, or any other suitable time period.

In a further aspect, the memory may be further configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to determine a sensitivity value associated with the analyte sensor, where the sensitivity value may include a ratio of the analyte data and the corresponding reference measurement.

The memory may be further configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to determine the rate of change based on determining a rate of increase or a rate of decrease of the monitored analyte level for a predefined time period.

A physiological monitoring device in still another aspect may include means for determining a rate of change of an analyte level monitored by an analyte sensor below a predetermined threshold, means for calibrating analyte data associated with the monitored analyte level received from analyte sensor based on a reference measurement, means for determining a time lag constant associated with the calibrated analyte data, and means for performing lag correction of the calibrated analyte data based on the determined time lag constant.

A method in accordance with one embodiment of the present disclosure includes obtaining a reference data point at a first predetermined time, receiving a first data at the first predetermined time, calibrating the first data based on the reference data point, receiving a second data at a second predetermined time, updating the calibrated first data based on the second data, and calibrating the second data.

The reference data point may include a blood glucose value.

The first predetermined time may include a calibration time associated with the calibration of one or more of the first data or the second data.

The first data and the second data may include a respective one of a monitored analyte value.

In one embodiment, calibrating the first data may include determining a first rate of change of the first data at the first predetermined time, and performing a first lag compensation of the first data based on the first rate of change to generate a first lag compensated first data. In a further embodiment, calibrating the first data may include determining a first calibration parameter associated with the first data based on the reference data point and the first lag compensated first data, and generating a calibrated first data based on the first calibration parameter and the first lag compensated first data.

Updating the calibrated first data in one embodiment may include determining a second rate of change of the first data at the first predetermined time based on the second data, and performing a second lag compensation of the first data based on the second rate of change of the first data to generate a second lag compensated first data.

Also, calibrating the second data may include determining a second calibration parameter associated with the first data based on the reference data point and the second lag compensated first data, and generating a calibrated second data based on the second calibration parameter and the second lag compensated first data.

A method in accordance with another embodiment may include determining a calibration parameter associated with a detected analyte value, calibrating the analyte value based on the calibration parameter, and dynamically updating the calibration parameter.

The method in another aspect may include calibrating a second detected analyte value based on the dynamically updated calibration parameter.

Further, dynamically updating the calibration parameter may also include determining a rate of change of the detected analyte value, and generating a lag compensated analyte value based on the rate of change.

In addition, calibrating the analyte value may further include determining a sensitivity associated with the detected analyte value, and applying the sensitivity to the lag compensated analyte value.

Moreover, in still another embodiment, dynamically updating the calibration parameter may include updating the rate of change of the detected analyte value, and updating the lag compensated analyte value, where updating the rate of change may include determining the rate of change of the detected analyte value between a first predetermined time and a second predetermined time.

In still another embodiment, calibrating the analyte value may include detecting a calibration data, determining a sensitivity based on the calibration data and the lag compensated analyte value, and generating a lag compensated and calibrated analyte value.

An apparatus in accordance with another embodiment may include one or more processing units, and a memory for storing instructions which, when executed by the one or more processors, causes the one or more processing units to obtain a reference data point at a first predetermined time, receive a first data at the first predetermined time, calibrate the first data based on the reference data point; receive a second data at a second predetermined time; update the calibrated first data based on the second data; and calibrate the second data.

The memory in another aspect may be configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to determine a first rate of change of the first data at the first predetermined time, and to perform a first lag compensation of the first data based on the first rate of change to generate a first lag compensated first data.

Moreover, the memory in yet another embodiment may be further configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to determine a first calibration parameter associated with the first data based on the reference data point and the first lag compensated first data and to generate a calibrated first data based on the first calibration parameter and the first lag compensated first data.

Additionally, the memory may still be further configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to determine a second rate of change of the first data at the first predetermined time based on the second data, and to perform a second lag compensation of the first data based on the second rate of change of the first data to generate a second lag compensated first data.

In yet still another aspect, the memory may be further configured for storing instructions which, when executed by the one or more processing units, causes the one or more processing units to determine a second calibration parameter associated with the first data based on the reference data point and the second lag compensated first data, and to generate a

calibrated second data based on the second calibration parameter and the second lag compensated first data.

A method in accordance with still another embodiment of the present disclosure includes, dynamically, and in particular embodiments, in real-time, obtaining reference data at a first predetermined time, receiving measured data prior to and including (or near) the first predetermined time, calculating a first calibration parameter (or parameters) using the data, calibrating the measured data based on the calibration parameter, receiving measured data at a second predetermined time, updating the calibration parameter based on all of the previous data and the newly received measured data, calibrating the newly received measured data based on the updated calibration parameter, and repeating a number of times the process of receiving new measurement data, updating the calibration parameter, calibrating the newly received measurement data, and calibrating any newly received measurement data with the fully updated calibration parameter.

A method in a further embodiment includes performing lag compensation on the measured data that is used to update the calibration parameter. Lag compensation may optionally be performed on the measured data that is calibrated. A method in a further embodiment includes filtering the measured data that is used to update the calibration parameter.

An apparatus in accordance with yet still another embodiment includes one or more processing units, and a memory for storing instructions which, when executed by the one or more processors, causes the one or more processing units to dynamically, and in particular embodiments, in real-time, obtain reference data at a first predetermined time, retrieve measured data prior to and including (or near) the first predetermined time, calculate a first calibration parameter (or parameters) using the data, calibrate the measured data based on the calibration parameter, retrieve measured data at a second predetermined time, update the calibration parameter based on all of the previous data and the newly received measured data, calibrate the newly received measured data based on the updated calibration parameter, and repeat a number of times the process of receiving new measurement data, updating the calibration parameter, calibrating the newly received measurement data, and calibrating any newly received measurement data with the fully updated calibration parameter.

A method, in one embodiment, may comprise, determining a predetermined time period characterized with a rate of change of an analyte level below a preset threshold, defining a data set associated with a monitored analyte level within the predetermined time period, determining a sensitivity value based on the defined data set, applying the determined sensitivity value to signals associated with the monitored analyte level including the defined data set, and estimating a time constant associated with an analyte sensor used to monitor the analyte level.

The preset threshold associated with the rate of change of the analyte level may be characterized by a quiescent state of the signals received from the analyte sensor.

In one aspect, the method may include receiving a reference data, and applying the sensitivity value to the signals associated with the monitored analyte level based on the received reference data.

The reference data may include a reference blood glucose measurement.

The reference data may be substantially time corresponding to one or more data in the defined data set.

The method may include calibrating the signals associated with the monitored analyte level based at least in part on the estimated time constant.

In another aspect, the method may include performing lag correction of the signals associated with the monitored analyte level based on the estimated time constant.

Further, the method may include calibrating the lag corrected signals to estimate the corresponding monitored glucose level.

In another embodiment, a computer implemented method may comprise, calibrating analyte data associated with a monitored analyte level received from an analyte sensor based on a reference measurement, determining a lag time constant associated with the calibrated analyte data, and performing lag correction of the calibrated analyte data based on the determined time lag constant.

In one aspect, the computer implemented method may include outputting the lag corrected calibrated analyte data.

The reference measurement may include a blood glucose measurement.

The reference measurement may be obtained within a predetermined time period relative to the monitored analyte level.

The predetermined time period may be less than approximately 30 minutes or greater than approximately 30 minutes.

Calibrating the analyte data may include determining a sensitivity value associated with the analyte sensor.

The sensitivity value may include a ratio of the analyte data and the corresponding reference measurement.

The analyte level may be a glucose level.

Determining the rate of change may include determining a rate of increase or a rate of decrease of the monitored analyte level for a predefined time period.

In one aspect, the computer implemented method may further include determining a rate of change of the analyte level monitored by the analyte sensor.

The rate of change of the analyte level may be determined below a predetermined threshold.

The analyte sensor may be configured to measure the analyte level based on coulometry.

The analyte sensor may be configured to measure the analyte level based on amperometry.

In yet another embodiment, an apparatus may comprise, a data communication interface, one or more processors operatively coupled to the data communication interface, and a memory for storing instructions which, when executed by the one or more processors, causes the one or more processors to determine a predetermined time period characterized with a rate of change of an analyte level below a preset threshold, define a data set associated with a monitored analyte level within the predetermined time period, determine a sensitivity value based on the defined data set, apply the determined sensitivity value to signals associated with the monitored analyte level including the defined data set, and estimate a time constant associated with an analyte sensor used to monitor the analyte level.

Various other modifications and alterations in the structure and method of operation of this invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. It is intended that the following claims define the scope of the present disclosure and that structures and methods within the scope of these claims and their equivalents be covered thereby.

What is claimed is:

1. A computer implemented method, comprising:

determining a rate of change of a monitored analyte level;

determining a lag time constant associated with calibrated analyte data using a reference measurement, the monitored analyte level, and the rate of change of the monitored analyte level;

performing lag correction of the calibrated analyte data based on the determined time lag constant; and

controlling administration of therapy based on performing the lag correction of the calibrated analyte data.

2. The method of claim 1, including outputting the lag corrected calibrated analyte data.

3. The method of claim 1, wherein the reference measurement includes a blood glucose measurement.

4. The method of claim 1, wherein the reference measurement is obtained within a predetermined time period relative to the monitored analyte level.

5. The method of claim 1, wherein determining the rate of change includes determining a rate of increase or a rate of decrease of the monitored analyte level for a predefined time period.

6. The method of claim 1, wherein the monitored analyte level is obtained using an analyte sensor.

7. The method of claim 6, wherein the analyte sensor includes one of a lactate sensor or a glucose sensor.

8. The method of claim 1, wherein determining the lag time constant includes pairing the reference measurement with an analyte sensor data corresponding to the monitored analyte level obtained when the reference measurement is obtained.

9. The method of claim 1, wherein determining the lag time constant includes pairing the reference measurement with an analyte sensor value based on a plurality of analyte sensor data corresponding to the monitored analyte level obtained before and after the reference measurement is obtained.

10. The method of claim 1, wherein the lag time constant is determined using multi-dimensional least squares technique.

11. The method of claim 1, wherein controlling administration of therapy includes modifying a medication delivery rate.

12. The method of claim 11, wherein the medication delivery rate includes one or more of a basal delivery profile or a bolus dose delivery profile.

13. The method of claim 11, wherein the medication delivery rate includes insulin delivery rate.

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